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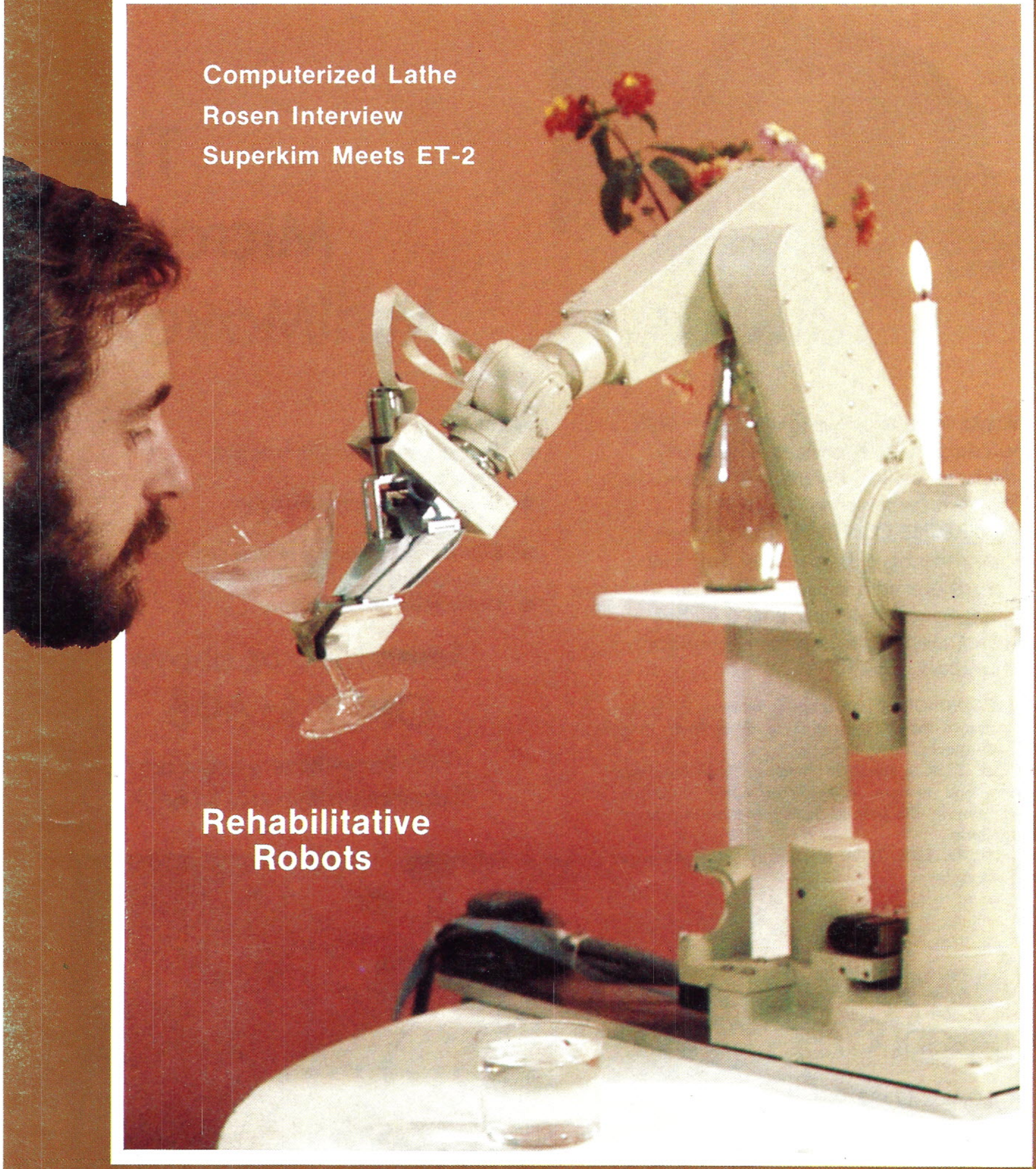

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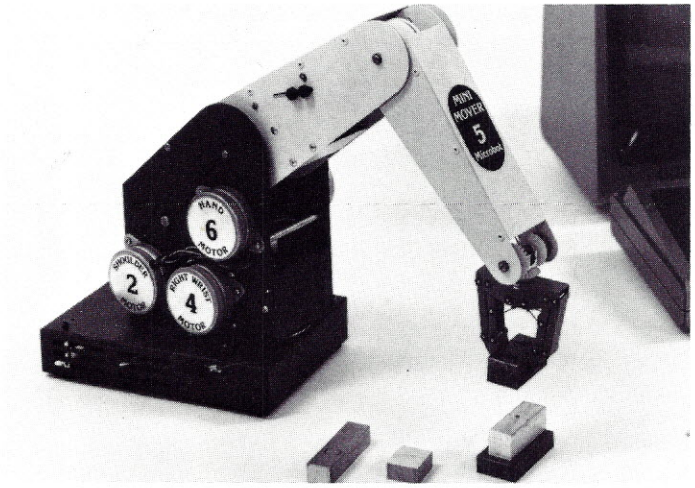

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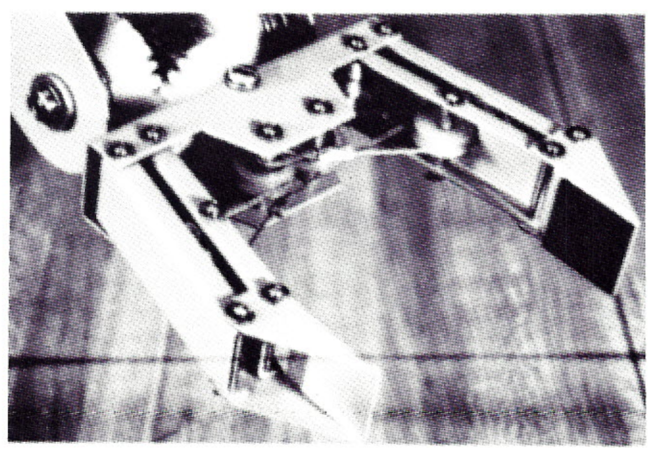

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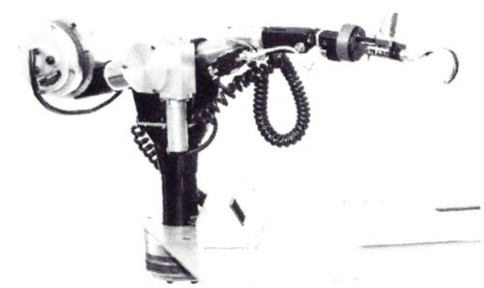
Articles



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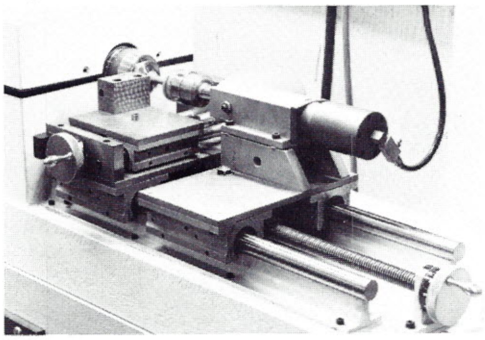

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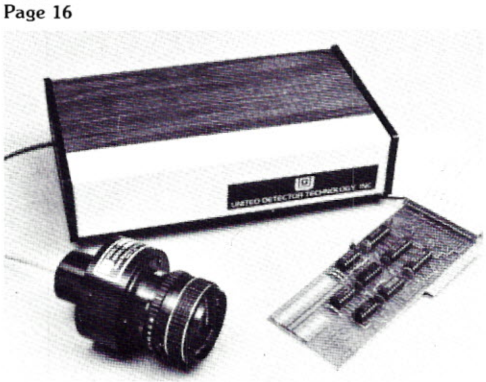

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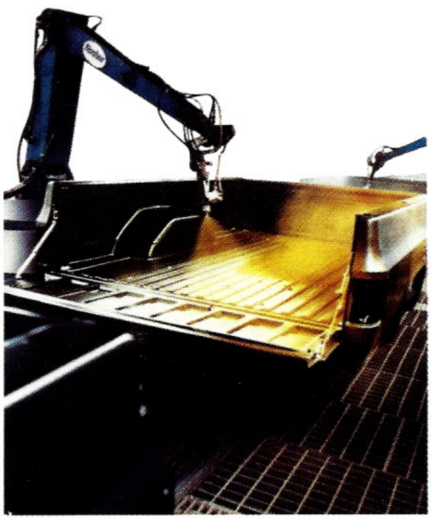

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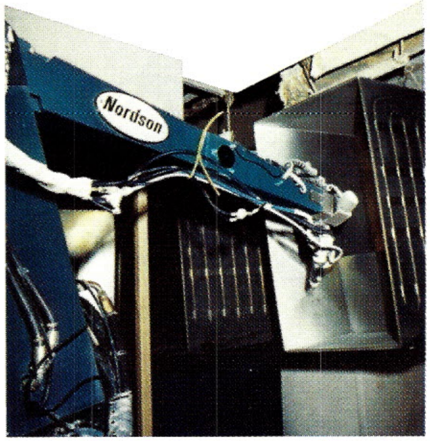

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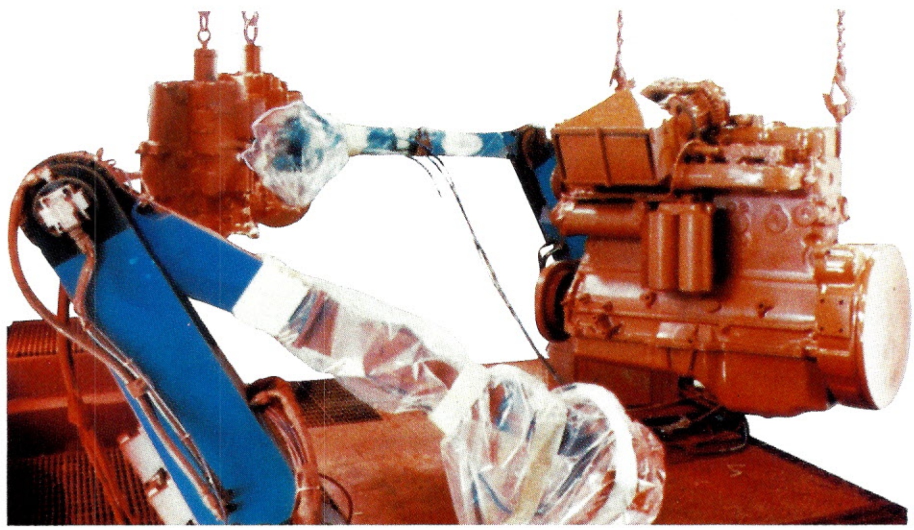

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CIRCLE 15

Rehabilitative Robots

by
Dr. Larry Leifer
Director of the Rehabilitative Engineering Research and Development Center
Veteran's Administration Medical Center
Palo Alto, California

This article, the first of a four part series, examines the objectives and evolution of Rehabilitative Robotics and defines specifications for an interactive robotic aid.

Man is a tool-using species. Our ability to manipulate our environment has given us the status we enjoy in the world today. We have created tools to extend this ability, culminating in programmable industrial automation—robots. Such robots are machines designed to manipulate other machines. We might think of robots as the ultimate result of our need to manipulate—they have the ability to take our place in many manual tasks.

To understand the importance of manipulation, just consider how much of the cerebral cortex is dedicated to hand and arm functions. Figure 1 caricatures a human body, drawn along the medial-lateral cross-section of the brain. Each part of the body is drawn in proportion to the number of neurons which respond to sensory stimulation or evoke motor output at that part. This representation—referred to as a *homunculus*—clearly shows the disproportionate amount of attention the human brain gives to our power to manipulate.

A severely disabled person has lost the power to manipulate. He is cut off from the direct control of his own personal space, impaired in performing personal maintenance functions, and cut off from the vast array of gadgets that most of us use in the course of our day.

Quadriplegia, paralysis of four limbs, is one disability that impairs the power to manipulate. It is typically the result of a traumatic spinal cord injury that disrupts neural tissue in the spinal column. When this happens at the level of the neck, the individual will have neither sensation nor muscle control in his trunk and legs. Depending on the details of the injury, the quadriplegic will have little muscle control or sensation in his arms. Grasp function is almost always lost. Respiratory function, because it is controlled from higher in the brain stem, is usually left intact. This injury occurs with increasing frequency, is seven times more likely to happen to males than females, and is most likely to happen to young people from eighteen to twenty-two years old.

In spite of an overwhelming loss of body function, a quadriplegic has no impairment of his mental faculties, and, with good medical handling, can have a normal life-expectancy. Though statistical data are sparse, I have estimated that the total cost of medical care and living support functions—for a twenty year old quadriplegic who lives the expected sixty-seven years—will be about two-and-a-half million (1980) dollars.

At the Rehabilitative Engineering Research and Development (RER&D) Center, in the Palo Alto Veteran's Administration hospital, we are working toward this goal: to give persons who are severely disabled, but mentally alert, physical control of their environment, without continuous assistance from other people.

We are applying advanced robotic technology toward this end, and are studying four areas in which we believe a disabled person can benefit from rehabilitative robotics: in activities of daily living, such as preparing food, eating, and personal hygiene; in personal clerical tasks, such as operating a calculator, computer, or telephone; in vocational tasks, such as computer programming or secretarial work; and in recreation—controlling electronic games, playing chess, or painting, for example. We believe that when a severely disabled person has the ability to manipulate he will become vocationally independent. Dignity and a higher quality of life should result from such independence.

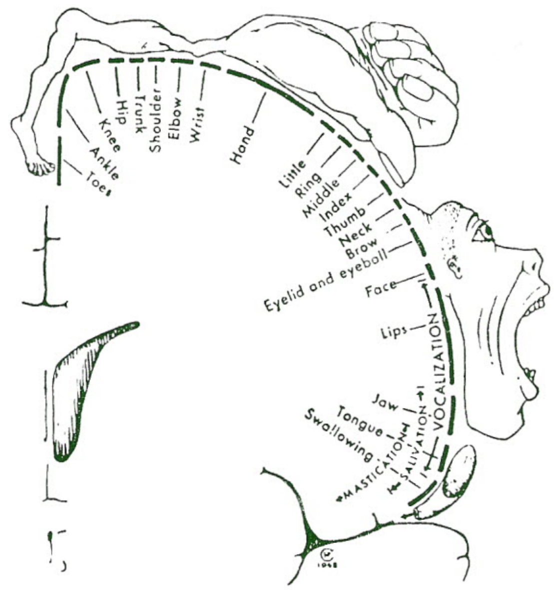

Figure 1. The allocation of human cortical capacity to sensory motor integration is visualized as a homunculus. The body is scaled so that the size of various segments is proportional to the number of neurons responding to or driving that portion of the body. It is clear that the arm and hand receive a disproportionate amount of attention. (Reproduced, with permission, from Penfield & Rasmussen: The Cerebral Cortex of Man: A Clinical Study of Localization of Function. Macmillan, 1950.)

Design Philosophy

Before reviewing the evolution of rehabilitative robots, let us examine the concept of rehabilitation that, so far, has guided the development of assistive devices. The dominant philosophy, implicit and explicit, has been to replace lost or damaged anatomy. Most designers of rehabilitative aids assume that a missing limb must be replaced. They try, in effect, to rebuild the disabled individual.

Unfortunately, when we try to rebuild anatomy we place severe constraints on the size, weight, power, and geometry of potential solutions. At present, when we improve the anatomical fidelity of a manipulator we lessen its functional performance. This fact led me to consider using industrial manipulators, rather than human-like arms, to help disabled persons satisfy their need to manipulate.

At the RER&D Center, we try to replace the missing limb's function, not its anatomy. The manipulation system should not pretend to be part of the user's body and need not be in physical contact with the user. However, the robotic aid should be handsome and worth including in the user's home. If we could not build a good-looking manipulator, then cosmetic criteria would fully justify replacing anatomy.

Our design philosophy is based upon the development of a single general-purpose system rather than a collection of special-purpose devices. Surrounding a disabled person with a clutter of rehabilitative gadgets will only further isolate him from people and public places.

A rehabilitative robotic aid must be interactive because it serves the constantly shifting attention of its user. It does not operate in the industrial context of repeated tasks. With an emphasis on flexibility, it must operate in largely unstructured environments and must be programmed in real-time. It represents the cutting-edge of robotics in the generic area of *Interactive Robotics.*

We have to consider two global value questions at each step in the evolution of Rehabilitative Robotics: how does one clinically evaluate a rehabilitative robotic aid to assess its benefit to the client and patient, and how much will it cost?

Clinical evaluation of the robotic aid is important and should be an integral part of the development plan. Assessment variables must be quantitative and objective. There is a long line of rehabilitative devices which have been developed, delivered to the patient or clinic and promptly closeted. Often the developer could have easily dealt with the problem if he had taken the time to consult the prospective users. In other circumstances, the device is not used because of psychological or social reasons, again not known to the developers. Had the designer explored these issues *before* technical development, he would have realized that the proposed device was irrelevant to the situation. Machines have no needs; only people have needs. It is imperative that robot designers establish and maintain a constructively critical dialogue with prospective users of their product.

At this time it is difficult to predict how the economics of robotic aids will evolve. However, the forces which propel development of industrial manipulators—especially labor costs—are also experienced by severely disabled individuals who must pay for up to twenty-four hour attendant care. Cost, reliability and service factors will depend upon progress in the industrial application of robotics. However, we can observe several important trends: First, the cost of computation is declining. In every other year one can obtain equivalent computational power for half the price (Turn, 1974). This factor affects the cost of voice recognition, voice synthesis, manipulator control, and sensory information processing. Second, as manipulators

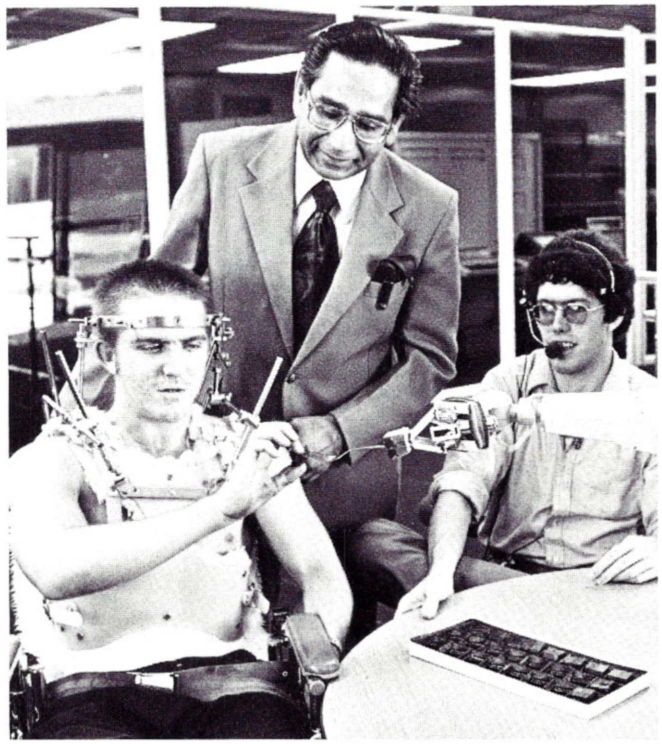

Figure 2. Veteran Asher Williams damaged his spinal cord at the neck level while diving. Mr. Williams was wearing a temporary head brace at the time of this photograph when he was participating in a project evaluation interview. He has since recovered considerable use of his arms. Dr. Inder Perkash (standing), Chief of the VA Spinal Cord Injury Service in Palo Alto, California, is a co-investigator on the VA sponsored Rehabilitative Robotics Project.

are produced in larger numbers, their cost per unit will fall. Currently the number of industrial manipulators produced yearly is in the low hundreds. It is expected to reach the tens of thousands by 1985. Finally, rising labor costs and declining productivity are contributing to increased investment in automation. A parallel phenomena in medical care makes the use of robotic aids increasingly attractive in rehabilitation.

There are three conditions a robotic aid must fulfill before it can economically substitute for human caretaking:

1. It must manipulate well enough to replace some classes of human assistance;
2. It must be reliable enough to encourage the user and his attendants to use it;
3. It must save (or earn) enough money to pay for itself.

To my knowledge, all previous projects have failed on one or more of these criteria (see reference Table 1). Yet I believe that the time is correct to develop powerful and economic robotic aids for the physically disabled. The necessary technology is evolving rapidly, industrial robots are now commercially viable, and the "independent-living movement" has become widely accepted among disabled individuals. Universities and industry have the technology. Technology transfer should now be carried out by the individuals who created that technology—guided by the people who need it.

Technical Considerations

There are three classical technical questions that we must consider at each step in the evolution of Rehabilitative Robotics:

1. How does the human user input command and control information to the robotic aid?
2. How does the robot process new inputs in the context of its current operation to produce a smooth manipulative sequence?
3. How is the robot's performance output communicated back to the human user?

The robotic aid must be able to accept both *commana* and *control* input from the disabled person. Command, usually accomplished with a keyboard, refers to a discrete item of information which specifies a task, operating mode,

Table 1 (a thru d)

Table 1a Critical review of projects in which manipulators were adapted for the physically disabled; approximate chronological order; prosthesis projects not included; DF = degree-of-freedom; R = rotational; T = translational.

Project	Arm	Discrete Inputs	Continuous Inputs
1 CASE version.1 floor mounted	laboratory 4DF, 4R, 0T 1kg lift	photo switches brow switches	none
2 RANCHO chair mounted	orthosis 6DF, 6R, 0T 1kg lift	6 tongue switches	2DF manipulandum
3 HEIDELBERG floor mounted	industrial 5DF, 5R, 0T 20kg lift	2 tongue contacts 1 suck&puff	3DF mouth manipulandum
4 VAPC chair mounted	rehabilitative 4DF, 3R, 1T 2kg lift	5 position switch	2DF chin manipulandum
5 JPL (VAPC derived) chair mounted	rehabilitative 6DF, 5R, 1T 1kg lift	36 words	none
6 UCSB table mounted	same as JPL 6DF, 5R, 1T 1kg lift	10 words	none
7 DENVER table mounted	same as JPL 6DF, 5R, 1T 1kg lift	1 tooth click	2DF eye tracking
8 JOHNS HOPKINS table mounted	prosthesis 5DF, 5R, 1T 2kg lift	1 switch keyboard	1DF chin manipulandum
9 SPARTACUS floor mounted	industrial 6DF, 6R, 0T 3kg lift	16 vox patterns 1 switch keyboard	6DF, head, elbow, hand, manipulandum
10 SPAR chair mounted	rehabilitative 5DF, 3R, 2T 2kg lift	2 switches	3DF manipulandum
11 STANFORD (PROPOSED) table mounted self-powered	industrial 6DF, 6R, 0T 1kg lift	100 words head motion keyboard	3DF head motion manipulandum

Table 1b Critical review of projects in which manipulators were adapted for the physically disabled; approximate chronological order; prosthesis projects not included; W = world coordinates; T = tool coordinates.

Project	Control Modes	Automatic Routines Capability	User Programming
1 CASE version.1	joint velocity	position replay	none
2 RANCHO	joint on/off velocity	none	none
3 HEIDELBERG	cylindrical velocity	none	none
4 VAPC	Cartesian (W) velocity	none	none
5 JPL	joint on/off velocity	none	none
6 UCSB	joint on/off	none	none
7 DENVER	Cartesian (W) position	none	none
8 JOHNS HOPKINS	joint velocity	limited	limited
9 SPARTACUS	Cartesian (W,T) position velocity	limited	none
10 SPAR	joint velocity	none	none
11 STANFORD (PROPOSED)	joint Cartesian (W,T) position velocity	locate/avoid grasp surface follow	unlimited sequence stack, run stored programs

Table 1c Critical review of projects in which manipulators were adapted for the physically disabled; approximate chronological order; prosthesis projects not included; modified 3 level rating scale (low, medium, high).

Project	Sensory Functions	Hand	Learning Difficulty
1 CASE version.1	none	2 finger vise	very high
2 RANCHO	none	braced hand 2 finger hook	very high
3 HEIDELBERG	none	pneumatic 2 finger vise + poker	medium
4 VAPC	none	2 finger hook	low medium
5 JPL	none	2 finger hook	high
6 UCSB	none	2 finger hook	medium
7 DENVER	none	2 finger hook	low medium
8 JOHNS HOPKINS	none	2 finger hook + suction	medium
9 SPARTACUS	10cm optical grasp force vertical force	2 finger 4 bar linkage removable	low very flexible
10 SPAR	none	2 finger hook	high
11 STANFORD (PROPOSED)	4mm optical 100mm optical grasp force	2 finger 4 bar linkage modular	low very flexible

Table 1d Critical review of projects in which manipulators were adapted for the physically disabled; approximate chronological order; prosthesis projects not included; modified 3 level rating scale (low, medium, high); low price $<$\$10,000; medium $<$\$20,000; high $<$\$50,000.

Project	Manipulation Capability	Reliability	Arm Price Control Price
1 CASE version.1	medium	medium	high very high
2 RANCHO	very low	high	low very low
3 HEIDELBERG	medium	medium	very high very high
4 VAPC	low	medium	medium medium
5 JPL	low	low	medium very high
6 UCSB	low	low	medium high
7 DENVER	medium	low	medium high
8 JOHNS HOPKINS	low	medium	low low
9 SPARTACUS	high	high	very high very high
10 SPAR	very low	medium	very high very low
11 STANFORD (PROPOSED)	high	high	

datum, or label. Control, typically done with a joystick or steering wheel, refers to continuous input functions, such as those required to pilot a vehicle. Possible control inputs include head displacements, jaw displacements, eye displacements, tongue displacements, respiratory pressure patterns, vocalization patterns, electromyographic activation patterns and electroencephalographic activity patterns.

In most man-machine interfaces, the human hand performs both command and control functions. For the quadriplegic this is impossible. Unfortunately, alternative channels are poorly understood. Head displacements are limited in range and speed. Their precision has not been evaluated quantitatively. While the human voice is capable of making thousands of utterances, computers can recognize only one or two per second (a high information bandwidth with a low temporal bandwidth). The physiological signal channels (electromyogram and electroencephalogram) are conceptually elegant but unreliable. In the case of eye movement command/control, we must be careful not to impair the normal function of an already vital information channel.

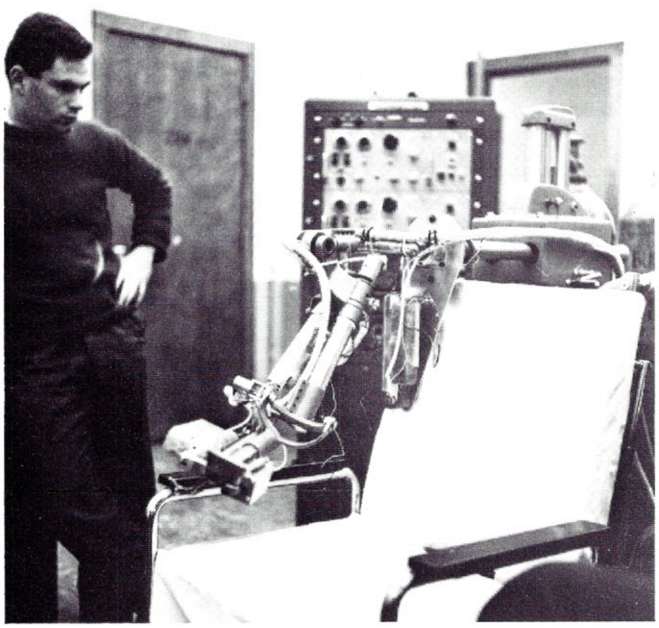

Figure 3. The Case Institute of Technology computerized orthosis was the first application of robotics technology to a rehabilitative manipulator. This 4 degree-of-freedom device was designed to carry the user's paralyzed arm while performing prerecorded manipulation tasks. Motion sequences were taught to the system by an able–bodied assistant during training sessions.

We believe that an interactive manipulator interface should use a variety of command/control channels tailored to the task at hand. The interface could include automatic computer control to coordinate individual joint motions, manage grasp/release reflexes, and control precise trajectories; voice command to enter data, select modes, identify objects, and call stored programs; synthesized voice feedback to appraise the user of system status information, express error conditions and provide usage prompts; and analog head displacements to pilot the manipulator in real-time.

We should remember that fatigue is usually proportional to the amount of conscious attention needed by the control task. Accordingly, input modes should be amenable to subconscious performance.

As the robot processes human input, the information transfer between man and machine must be carefully managed. Every physical disability reduces our capacity to transmit, receive, or process information. Therefore, we should have the user specify goals, the system attempt to acheive those goals, and the user supervise the system's operations. Of course, the exact division of labor between man and computer will vary according to the task. The following examples delineate the system control modes we believe are necessary at this time:

1. *Open Loop* performance of predetermined trajectories and trajectory sequences;
2. *Closed Loop* tracking of a target in six degrees of freedom (6–DF:X, Y, Z, roll, pitch, yaw);
3. *Manual*, "teach" mode operation;
4. *Background* command entry and program editing:
5. *Foreground* performance of the manipulation task;
6. *Reflex* control of grasp, obstacle avoidance, and unplanned human contact;
7. *Hierarchical Command* and *Control* structures which place the user at different positions in the control network:
   a. *Man-in-the-Loop*, direct control;
   b. *Supervisory Command*, auto-pilot mode;
   c. *Mixed Mode*, 6-DF command with 2-DF control.

The usefulness of artificial limbs had been limited mainly by inadequate sensory feedback. Movements performed open loop, without sensory feedback, are awkward. Visual feedback of gross limb displacements is not as easy to manage as kinesthetic feedback. Unlike muscle, tendon, and joint sensation, visual feedback requires constant attention. Constant attention fatigues the user and dimi-

nishes his ability to attend to other stimuli.

We are faced with the same problem at the performance feedback interface that we had at the command input interface: human channel bandwidths are limited and poorly understood. At this time we can best proceed by minimizing the amount of information the user is required to process. If possible, the system should process sensory data to the point of making manipulation decisions. The user can then supervise the outcomes of those decisions. The human role is one of task selection, command generation, and performance supervision.

The user needs some performance feedback. The robotic aid designer should consider using vibro-tactile stimulators, electro-tactile stimulators, visual displays, auditory codes, or voice response as output channels.

Using the design considerations discussed above, we can now envision a typical rehabilitative robotic aid. The aid should include one or more electro-mechanical arms which the user can move about the environment to perform useful work; one or more microcomputers to control the arm(s); one or more input channels to give the user complete command and control of the robotic system; and, finally, one or more feedback channels to make the user conscious of the arm's performance.

The Evolution of Rehabilitative Robotics

Since the dawn of pre-history, man has tried to extend his power of manipulation beyond the limits of his flesh. *Telemanipulators*, extensions of man's arms and hands, were the first fruits of this drive. Telemanipulation was first used for rehabilitation in the form of prosthetics—anatomical replacements for lost arms or legs.

Rehabilitative engineers have often tried to build externally powered prosthetic arms, only to be severely hampered by weight and power constraints. Most designers prefer body-powered artificial arms because the user then has some sensory feedback on limb performance. Attempts to control the prosthesis with electromyographic (EMG) signals from residual muscles have been frustrated by the user's need to consciously maintain visual attention to the terminal device. Though efforts to do adaptive EMG signal processing (Graupe et al, 1977) are promising, the lack of sensory feedback remains a problem. Some designers have attempted to build tactile displays for joint and grasp feedback; but these displays are not included in production prostheses (Solomonow and Lyman, 1977). Even the most sophisticated prostheses do not incorporates any computational capability.

While engineers have built prostheses for persons with missing limbs, they have built *orthoses* for those with paralyzed arms. An *orthosis* is an exoskeletal structure that supports and moves the user's arm.

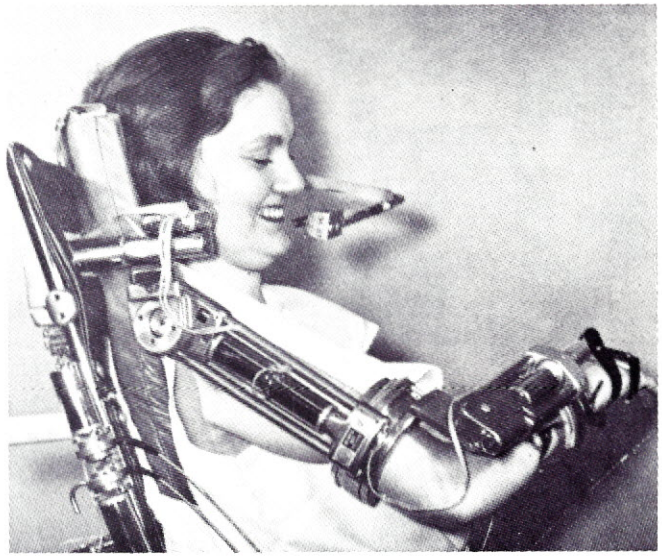

Figure 4. The Rancho Los Amigos Orthosis had 7 degrees-of-freedom. It was the first electric orthosis ammenable to external control. Joint specific control was accomplished with mechanical switch arrays. One of these arms was interfaced to the Stanford Artificial Intelligence Laboratory DEC-10 as part of a proof-of-concept demonstration.

This line of development produced the first computer-manipulator system, at Case Institute of Technology during the early 1960's (Figure 3). The Case four degree-of-freedom (4-DF) externally powered exoskeleton carried the paralyzed user's arm through a variety of manipulation sequences (Reswick and Mergler, 1962; Corell and Wijinshenk, 1964). In the first of two versions, the system performed preprogrammed motion. The user initiated the motion by pointing a head-mounted light beam at photoreceptors mounted in a structured environment. An able-bodied assistant, moving the orthosis manually, taught arm-path sequences to the system. While stored digitally, the data were effectively analog. By using numerically controlled pneumatic actuators with feedback from an incremental encoder, the system achieved closed-loop position control.

In an upgraded second version, a minicomputer performed coordinate transformation along X, Y, and Z axes. Case employed electromyographic (EMG) signals to specify endpoint velocity within this coordinate space. Photo-receptors, mounted on each arm segment, could be used to control individual joint displacements. In the sense of having a stored operating code, neither version was programmable. Yet this was a milestone project in many respects. For more than ten years, no other project employed the technology or concept of computer-augmented manipulation with as much sophistication.

The Rancho Los Amigos Manipulator (Figure 4) was designed as an orthosis with seven degrees-of-freedom. It

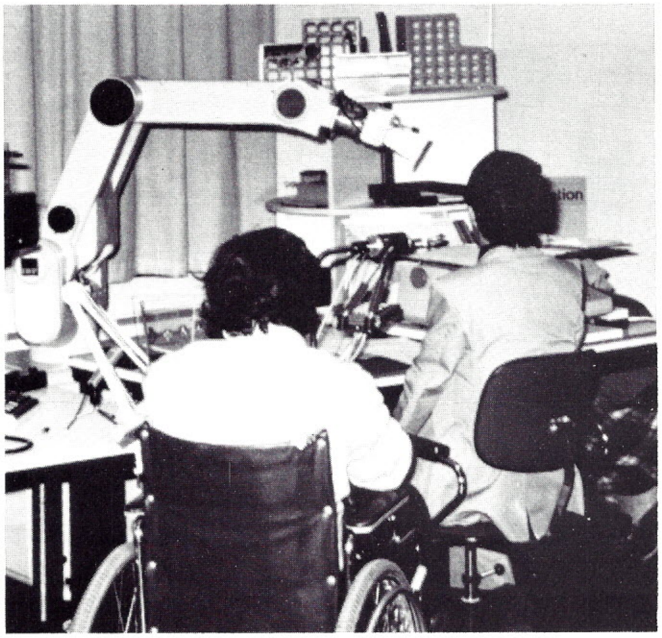

Figure 5. The Heidelberg manipulator and structured work station was the first rehabilitative application of an industrial manipulator. The system used a minicomputer for end-point control in cylindrical coordinates. The user controlled the manipulator at all times. They decided against computer augmentation of the task.

followed the design philosophy of the Case system but did not augment manipulation with computer control. It used direct current servo motors at each joint and controlled each motor with a variety of ingenious switch arrays. Several similar versions of the "Golden Arm" were built. At least one version was wheelchair-mounted and battery-powered. General Teleoperators (Jim Allen, president and principal designer) still offers manipulators descended from this line of evolution.

Extensive clinical trials confirmed the impracticality of joint specific control. These trials confirmed results from the Case group and underlined the need for computer augmention. Moe and Schwartz (1969) computerized the Rancho Arm to provide coordinated joint displacement and proportional control. In 1971, Freedy, Hull and Lyman studied the feasibility of using a computer to adaptively help the user control the manipulator.

These efforts, though, could not overcome limitations inherent in the orthosis. In 1979, Corker et al, evaluated remote medical manipulators. They observed that fitting a manipulator to the specifics of an individual's anatomy and range of motion makes construction and control very difficult. Furthermore, there is no functional reason for the manipulator to carry the user's arm, which has neither grasp nor sensation. In fact, there is a danger of injury because the user's arm could be driven beyond its physiological range without any warning sensation. The orthotic approach is a clear case of anatomical replacement thinking. This line of evolution in rehabilitative telemanipulation is effectively extinct.

As an "evolution of the species" footnote, I should mention that Victor Scheinman and I purchased one of the Rancho orthoses in 1964 for the then-budding robotics project in the Stanford University Artificial Intelligence Laboratory (SAIL). We instrumented the arm for joint position feedback and interfaced it to a DEC PDP-10 computer. Preliminary experience with computer control of that arm helped establish reliability as the most important performance criteria.

In the late sixties and early seventies, work began with manipulators which were physically isolated from the user

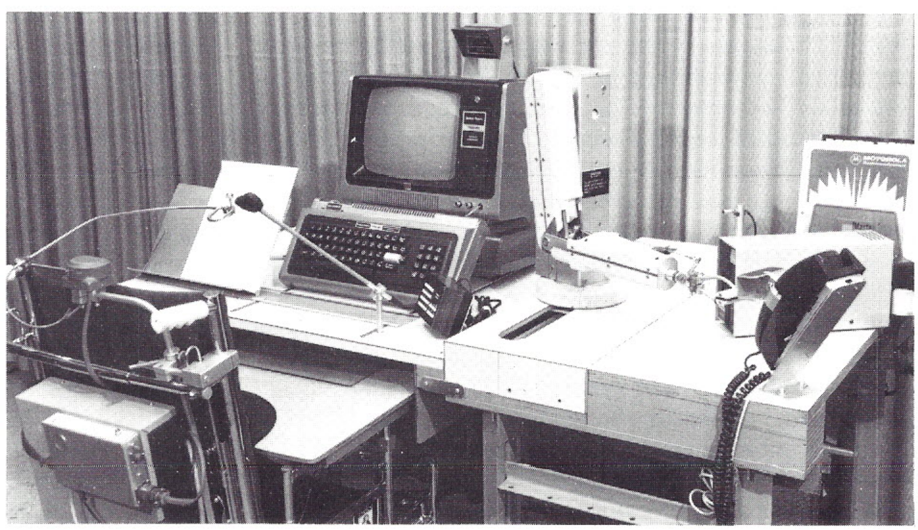

Figure 6. The Johns Hopkins University Applied Physics Laboratory manipulator and work station evolved from the goal of developing a prosthesis. Like the Heidelberg system, the applications environment is highly structured. Their experience with semi-automated feeding suggests that computer augmented manipulation may be well received by users and their attendants.

and made no pretext of being limb replacements. The designer was now free to follow the dictates of efficient machine design for computer control. In 1969, working with remote master-slave manipulators, Whitney formalized the concept of resolved motion rate control. Whitney's work helped lead to the use of end-point control in robotics and to computer augmented remote manipulation. In 1974, Roth demonstrated that for certain geometries one can efficiently and explicitly solve all of the manipulator configuration alternatives (for 6-DF) to minimize a variety of parameters (such as net joint displacement for a specified point-to-point path length).

Roesler and Paeslack, in 1974, at the University of Heidelberg, were the first to use an industrial manipulator and a highly structured work environment (Figure 5). The electromechanical manipulator had five degrees-of-freedom plus grasp. The floor-mounted manipulator was about 1.3 times human scale and occupied a fixed location within the work station. The Heidelberg manipulator used a minicomputer to transform coordinates for end-point control in cylindrical coordinates. They used computer augmentation to store intermediate points of special interest and to integrate the status of many special purpose devices within the environment. Among the devices were a modified telephone, special typewriter, custom mouth-stick keyboard, motorized parts bin, and a three degree-of-freedom mouth manipulandum.

In this system, the user controlled all movement. However, the system did not allow the user to program the manipulator, nor did it execute preprogrammed manipulation sequences. This appears to have been the result of cultural or investigator bias, since the developers report that prospective users stated a clear preference for direct control at all times. Social and cultural factors are crucial in determining system specifications. In this case, they may have prevented the Heidelberg group from fully using the technology and expertise vested in the project.

A conceptually similar manipulation work station was developed by investigators at the John Hopkins University Applied Physics Laboratory (Seamone, et al., 1978; Schneider, et al., 1981). Their four degree-of-freedom manipulator (plus grasp) was human scale, having evolved from a prosthesis for shoulder-level amputees (Figure 6).

Though overweight and underpowered, the prothesis was successfully adapted to limited microprocessor control. One DC torque motor drove elbow flexion-extension, wrist pronation-supination and shoulder flexion-extension. Cable-driven spring-return mechanisms with solenoid-actuated locks isolated the shared degrees-of-freedom. A second motor drove shoulder rotation and grasp. The arm was mounted on a translation table that provided one additional degree-of-freedom, enlarging the manipulator's working volume. Simultaneous motion on all axes was precluded by the motor drive design.

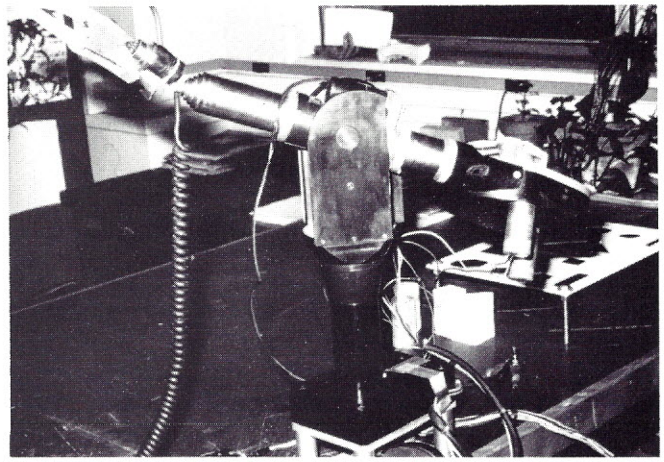

Figure 7. A telescoping 4 degree-of-freedom powered reacher developed at the VA Prosthetics Center in New York (now the VA Rehabilitation Engineering Center) used analog electronics to effect end-point velocity control. A derivative of this design by General Teleoperators added two additional degrees-of-freedom at the wrist. In this form the manipulator has been adapted to voice command, eye-motion control and wheelchair mobility. Reliability problems have severely hampered the further evolution of the system.

The John Hopkins system used preprogrammed manipulation sequences for standard tasks such as book retrieval from fixed storage bins and food service from specified serving bowl locations. The user could define, enter by keyboard, and store ten motion sequences for later execution. John Hopkins' experience with semi-automated self-feeding supports the idea that users and their attendants respond favorably to some degree of automation and appreciate the independence it makes possible.

Carl Mason of the Veterans Administration Rehabilitation Engineering Center (formerly the VA Prosthetics Center) was the first to use a prismatic shoulder joint in a rehabilitative remote manipulator. The manipulator was designed to retrieve objects from the floor and overhead shelves. The earliest version had four degrees-of-freedom plus grasp and might be better referred to as a "powered reacher" (Figure 7). The device was used in both table and wheelchair-mounted settings. It was controlled by mechanical mode switches and a 2-DF chin manipulandum. Mason used analog electronics to obtain Cartesian velocity control. The device was not programmable.

Later, General Teleoperators used its design as a basis for several second-generation telescoping manipulators. Three additional degrees of rotational freedom were added to the wrist of these models (5-DF rotation, 1-DF translation). Researchers have used several such devices to study alternative approaches to handling the man-machine interface.

The NASA Jet Propulsion Laboratory (JPL) in Pasadena mounted one of these manipulators on an electrically powered wheelchair (Figure 8) and used a minicomputer-based voice recognition system to control the velocity of individual joints. JPL also used the voice system to command and control the wheelchair (Heer, et al., 1975). While the 36 word vocabulary should have been adequate, low recognition reliability and slowness discouraged further use of voice command.

Robert Roemer, at the University of California at Santa Barbara, adapted one of the 6-DF General Teleoperator manipulators to command-control by a microcomputer-based voice recognition unit. John Lyman's laboratory at the University of California at Los Angeles evaluated the system, and Corker, et al., reported preliminary results in 1979. In summary, the manipulator was not sufficiently reliable for clinical tests. The average recognition rate was 68.9%, too low to permit real-time interactive command-control of a manipulation task.

The Spartacus Project in France was the first to use a computer-augmented nuclear industry master-slave manipulator for rehabilitative purposes (Figure 9). The CEA-LaCalhene MA-23 manipulator had six degrees-of-freedom plus grasp (Guittet, et al., 1979). Control modes included discrete mechanical switches, a 3-DF manipulandum, mechanical head motion instrumentation, and laryngophone input. Theirs was the first robotic aid with optical proximity detectors on the terminal device. They accomplished computer augmentation with a minicomputer (SOLAR 16/65 with 48-k main memory) and included end-point control in both world and tool reference Cartesian coordinates. Position, velocity and motor current derived force control modes were available. These sensory capabilities provided the system with "reflexes" for precise object localization, and grasp. The manipulator was programmable in a high level language and capable of repeating preprogrammed motion sequences. At the time of their most recent publication, the system had no provision for user programming.

The manipulator itself, designed by Vertut, et al., (1976), uses DC torque motors, steel ribbon reversible transmissions, and analog position servo systems. In spite of its apparent size, the manipulator has relatively low inertia, high natural compliance, and limited reversible force output. The entire system weighs over 1,000 pounds and stands over two meters high—quite a formidable aid! The project has done pioneering work with sensors, control augmenting reflexes, and heirarchical control software. The Spartacus Project had all the ingredients of an interactive robotic aid, thought the MA-23 was too big for a domestic environment.

The VA–supported Stanford Robotic Aid is the first system to incorporate a human scale industrial manipulator (Unimation PUMA-250), a standard microprocessor

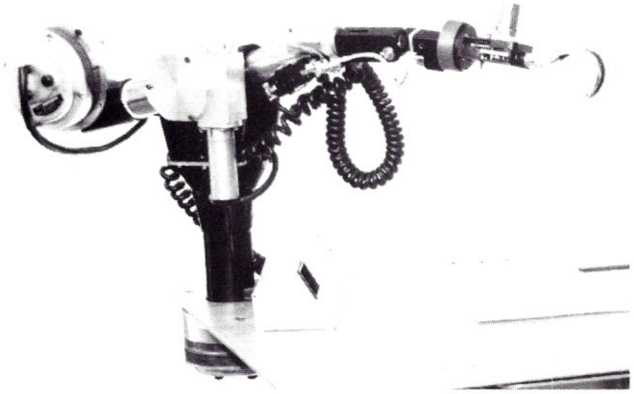

Figure 8. Researchers at JPL outfitted the General Teleoperators manipulator with a minicomputer based voice recognition system and mounted it on an electrically powered wheelchair. They attempted to control both manipulation and the wheelchair motion with voice commands. Manipulation was not computer augmented.

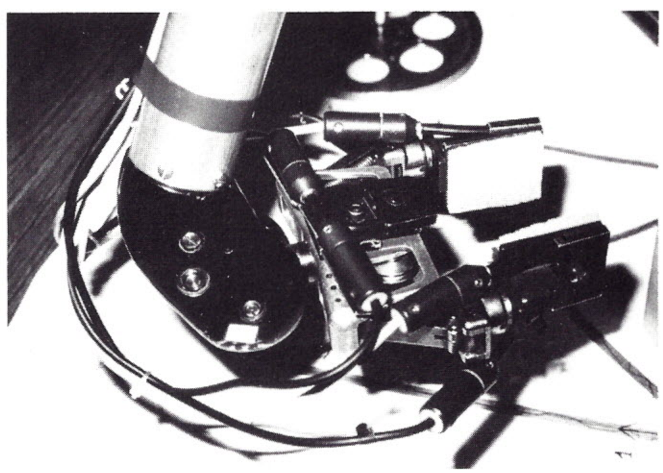

Figure 9. The French Spartacus project developed the first truly robotic aid. The system used a successful nuclear industry master-slave manipulator with six degrees-of-freedom and grasp (the CEA-LaCalhene MA-23 developed by Jean Vertut). A 16-bit minicomputer (SOLAR 16/65) was used for several levels of computer augmented manipulation. Proximity sensors on the two fingered hand were used to provide basic reflexes for grasp and object localization. Weighing over 500 kg (1200 pounds) and standing over 2 meters high (7 feet) without the computer rack, the system was simply too large for the domestic environment.

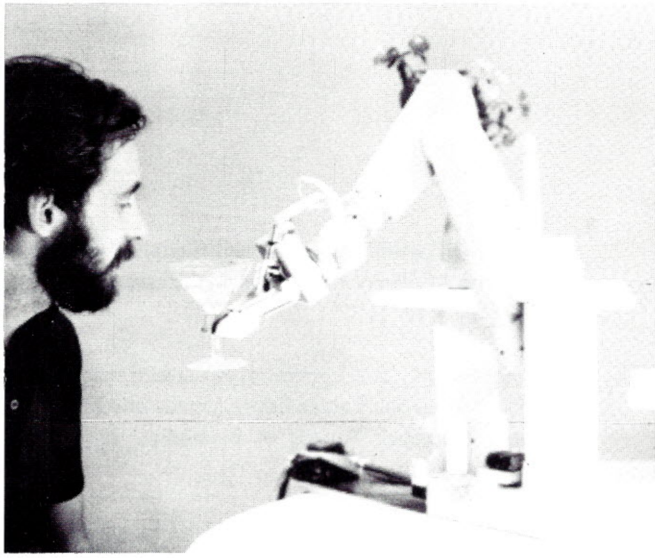

Figure 10. Stanford University's Robotic Aid is the most recent attempt to demonstrate the feasibility of using robotic techniques to satisfy the manipulative needs of severely disabled individuals. The system contains 12 microcomputers and is built around Unimation's successful human scale PUMA-250 programmable manipulator. Voice command and synthesized voice output with additive manipulandum input promise to give the user effective real-time interactive command and control of a wide variety of manipulation tasks. A smart sensate hand supports reflex control of grasp, object localization and object avoidance.

based voiced command unit, and mixed mode heirarchical control software running in five independent microcomputers (Figure 10). As reported [in Leifer 1980ab], the first version of this system is about to enter clinical pretesting. The six degree-of-freedom PUMA-250 is DC torque motor driven with incremental optical encoders in a digital position servo. Manipulation is controlled in the background while user interactions are monitored in the foreground of a BASIC-like operating sytem (VAL). The PUMA controller is a 16-bit DEC LSI 11/2 with 24K bytes of main memory. The VAL operating system occupies about 12K of PROM leaving 12K of RAM for user programs and coordinate transform data.

In the Stanford Robotic Aid, the PUMA controller is driven by a Z-80 based Zilog microcomputer system executive that integrates voice and sensor inputs with arm and voice outputs. Programs and data are stored on the executive system's dual 8″ floppy disk drives. Voice recognition and hand control units are both Z-80 based. The two-fingered hand incorporates twelve optical proximity sensors, half of which are short range (4mm), high resolution detectors (0.05mm), and the other half are long range (100mm), low resolution detectors (4.0mm).

In response to voice commands the system can do preprogrammed manipulation tasks, immediate mode movement control and deferred command sequences. The robotic aid has world, tool and joint coordinate systems available to it, and it can intermix coordinate systems in the command syntax. The system can mix voice initiated motion with joy-stick (head control unit) inputs during real-time manipulation. This project appears to have most of the ingredients needed to decisively test our hypothesis that robotic aids can help rehabilitate severely disabled individuals. I will discuss it in more detail in future articles in this series.

Conclusion

There are two dominant themes in the evolution of robotics. Along one path we observe the development of analog extensions to the human arm. I have referred to this approach as *Telemanipulation*. It includes the most primitive stick and the most advanced master-slave manipulator. The second evolutionary path features devices which have no physical connection to the human user. *Robotic Manipulation* is intended to augment function, not anatomy. Robotic devices typically follow commands, telemanipulators are controlled. I believe, as Figure 11 shows, that these two paths will give rise to a third approach, which I refer to as *Interactive Robotics.*

Rehabilitative Robotics is one application within the generic field of Interactive Robotics. Neither telemanipulation nor robotics in their pure form can satisfy rehabilitive needs. Telemanipulation fails because of man-machine

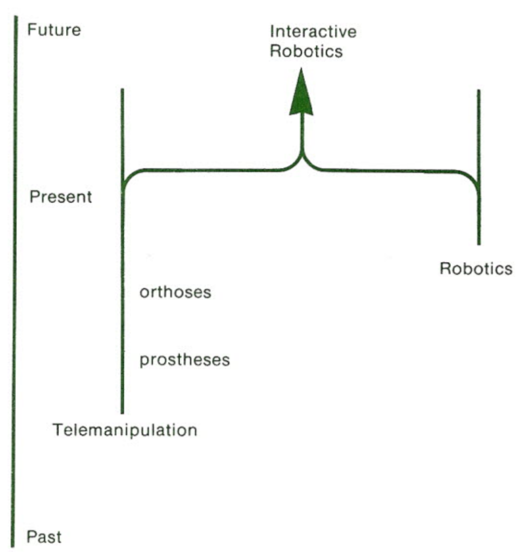

Figure 11. Interactive Robotics is a natural result of the evolution of telemanipulation and robotics. It is a consequence of human needs and the availability of necessary resources.

interface constraints encountered with disabled users. Robotics based solely upon computer control of electromechanical manipulators fails because the human living environment is much less structured than the industrial assembly environment, and because human needs change more rapidly than manufacturing tasks. We expect interactive robotics to become increasingly important within the industrial environment as robotic applications proliferate, users with less "computer tolerance" are accommodated, and task assignments become more complex and varied.

Industrial robotics is now strongly influencing the design of rehabilitative aids. I think, though, that the lines of influence may yet run in both directions. Though designed to aid the physically disabled, interactive robotic systems will have important consequences within the field of robotics.

Acknowledgements

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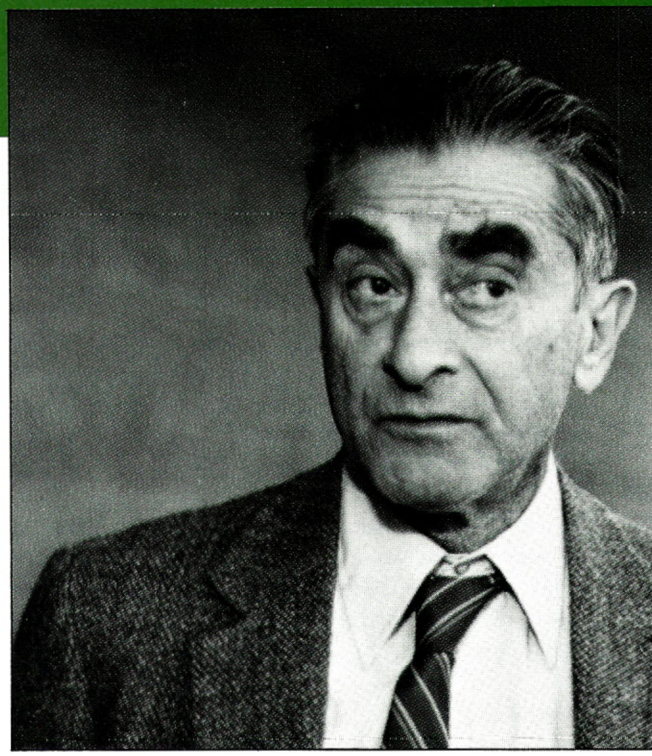


By Jerry W. Saveriano

AN INTERVIEW WITH CHARLES ROSEN

A pioneer in Advanced Robotics, the founder of Machine Intelligence Corporation talks about the development of intelligent machines and the forces that are taking them into the factory and beyond.

To the youngest generation of roboticists, Dr. Charles Rosen's name is linked to that of Machine Intelligence Corporation (MIC). They know of Charlie as the founder of MIC and the chief scientist of the group that developed the VS-100 vision system.

To a more seasoned generation of roboticists, though, Charlie is also known as the founder of the Artificial Intelligence and Industrial Automation groups at Stanford Research Institute (SRI) and the project leader of SRI's robot project—SHAKEY. For more than twenty years, Charlie has been actively promoting and managing projects to develop advanced automation.

Charles A. Rosen was born in Toronto, Canada in December, 1917. As a young student in Canada he was involved in amateur radio projects, and interested in popular science, science fiction magazines, and the emerging field of electronics.

Educated in U.S. and Canadian colleges, he earned a B.S. degree in Electronic Engineering from Cooper Union in 1940, a Masters Degree in Manufacturing Engineering from McGill University in 1950, and a Ph.D. in Electronic Engineering from Syracuse University in 1956.

He worked with the British Air Commission in Canada during World War II, where he trained technicians in Aircraft Electronics, and helped build and test planes for the U.S. Navy.

Soon after the war, Charlie immigrated to the U.S. and became a research engineer in General Electric's electronics laboratory. There, Charlie helped build one of the largest groups in the country doing research on transistor circuits. He also co-authored, in 1952, the first textbook on junction transistor circuits.

In 1957, Charlie left General Electric's Syracuse facility for California. Though he had several attractive offers, Dr. Rosen accepted a research position at SRI because of its receptiveness to new research projects.

The rest is history—which we had best let Charlie tell in his own words.

How did work in Artificial Intelligence (AI) begin at SRI?

Our work in AI actually evolved out of an interest in micro-electronics. The first important step occurred when a guy came through the door, named Ken Shoulders, who had a dream of being able to make micro-electronic devices using an electron beam machine. That was around 1958-59, roughly. He sold me on the idea that one could, using thin films, make structures that would function as active devices. I hired him—and we began working on ultra vacuum systems, electron optics, electron beam machining, and thin films, long before any of that work went on in the Bay Area.

Then, about a year and a half later, by a fortuitous circumstance, a man by the name of Frank Rosenblatt came by, touring the U.S. and looking for help to build a new kind of machine. He wanted a device that he could use in a thing he called a *perceptron*. This was a learning machine that, in its simplest form, performed a weighted sum on a number of inputs and produced an output depending on whether or not the sum exceeded a certain threshold. With a scheme for varying the weights and thresholds and for organizing the simple units into systems, perceptrons could be taught to perform various pattern-recognition tasks. Frank Rosenblatt sold me on the general idea of perceptrons, training machines, and learning machines, and I said "yes, we'll try and make that device you need." This wasn't such a wild idea because, at that time, Shoulders was trying to make active devices by the billions with thin films. Shoulders wanted to make a computer-like brain. And here came Frank Rosenblatt who said "I know of an architecture you could use to make a learning machine if you had enough of the right devices." I thought that with Rosenblatt, we'd learn how to organize Shoulder's little devices to build useful machines. The two pieces looked right—they fit in the right place.

We put on our high heels and went to the government—here, there, and everywhere—and managed to sell some contracts to the Navy, and to the Signal Corps—and we started. For a while we builtup perhaps the biggest group in the world working on perceptron electronics. That's when I began hiring some of the people whose names are very famous in Artificial Intelligence today. I hired Nils Nilsson, Dick Duda, Peter Hart, John Munson, and Ted Brain—just to name a few. We hired them all to build perceptron learning machines.

When did you start working with perceptrons?

In the early sixties—'60, '61, '62. You know, it was pretty early. There were some computer companies, but at that time we weren't using computers for our machines. We started by building our own computational units with what we had. We didn't have chips—it was pretty early in the game—we had only transistors and tubes! Transistors were just beginning to be used for computers to some extent.

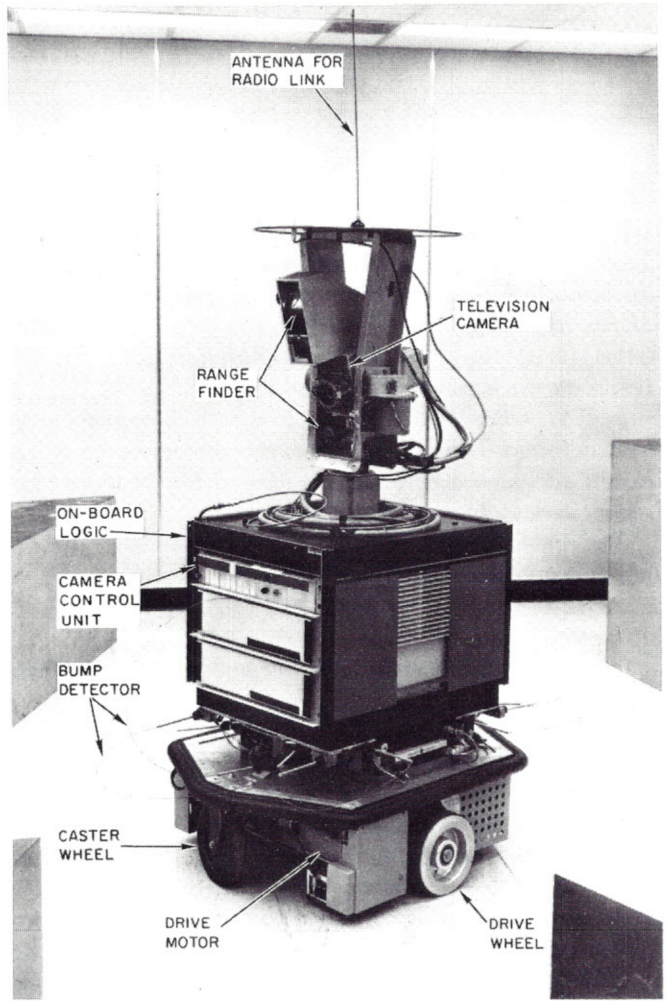
"We got beyond the thought that there's something mysterious about what happens in our heads, that it's not possible for physicists, chemists, and information scientists to learn how we think. There are still many people, smart people, who say it'll NEVER be done. They're out of their minds! They're still looking for some mysterious energies or soul or what have you."

When did people start to recognize Artificial Intelligence as a distinct discipline? When did they start to use the term, "artificial intelligence"?

The term "artificial intelligence" was started by McCarthy and Minsky at MIT about the time I began working with perceptrons. Newell and Simon at Carnegie, and Minsky and McCarthy at MIT, aided by about four or five others, were the people who thought it was possible to make intelligent machines. They preceeded my entry into the field by about three years.

In any case, AI was born from the point of view that something could be done using machines—computers, of course, were a possible route, though not the only route—for doing things that humans do. We got beyond the thought that there's something mysterious about what happens in our heads, that it's not possible for physicists, chemists, and information scientists to learn how we think.

“...we began to build SHAKEY. For the first time in one system, we put together an advanced sensor—a vision system, a very large computer system tied by radio to the equipment, computer-controlled motors, a path-finding planner, and even a certain amount of problem-solving.”



There are still many people, smart people, who say it'll *never* be done. They're out of their minds! They're still looking for some mysterious energies or soul or what have you. These early AI researchers felt that an intelligent machine could be built.

Was there any relationship between SRI and the Artificial Intelligence work done at Stanford?

Let me make this clear: one organization was never part of the other. SRI has always been a separate, non-profit organization. The purpose of SRI's original charter was to create an R&D organization the would help western business. As its charter grew, SRI became a self-sustaining organization to help *anybody* do research and development. As it happenned, though, Stanford started SRI. At the beginning, the directors of SRI were chosen by Stanford. Therefore, Stanford did have a lot of influence on SRI's policies. Direct influence was split off in the late sixties, when students didn't want Stanford to be attached to anyone who was doing work for the Department of Defense (DoD). Now, SRI is a completely autonomous organization.

How did you make the transistion from perceptrons to the type of research now being done in AI?

After a while, we began to see the limitations of perceptrons. We realized that they didn't have the general power of a digital computer. Perceptrons had limited functions—such as the weighted sum of inputs—while computers had a full range of branching and logical operations.

Minsky and Papert mathematically proved that under certain constraints, certain classes of perceptrons were limited in capability. But by that time, our group at SRI had already stopped doing work in perceptrons. Personally, I think Minsky and Paperts' work was a mixed blessing: On one hand it provided a good mathematical treatment of perceptrons, but on the other, it discouraged further work in that area. I still feel that a great deal of work can be done with a threshold logic or perceptron type of device. Today it is possible to replace the simple weighted summation units used in perceptrons with complete processors.

In any case, soon we were no longer making little bits and pieces to go into learning machines. We were actually simulating learning machines on a small computer. That's when we bought our first computers and became adept at using them. None of the people in our group had worked with computers. They came from electrical engineering, physics, or allied sciences.

The work on pattern recognition—which we began with perceptrons—we now expanded, using powerful new techniques on general-purpose computers. We did extensive work in scene analysis.

By this time, we thought we could spread our wings and begin to do work in other areas of machine intelligence as well. After snooping around quite a bit and looking at what we could do, we decided to try to build a robot.

Why a robot?

I wanted to build a robot because I felt that if we could do vision, task planning and knowledge representation—

the work that is going on in AI right now—we could have capabilities far more advanced than we could have with pattern recognition or a limited learning machine.

We took a year and a half to sell the program to the Department of Defense. Our first contract was on the order of a couple of hundred thousand dollars for the year, and with that we began to build SHAKEY. For the first time in one system, we put together an advanced sensor—a vision system, a very large computer system tied by radio to the equipment, computer-controlled motors, a path-finding planner, and even a certain amount of problem-solving. It was a real testbed for breaking our teeth into nearly every branch of artificial intelligence.

How long did the SHAKEY project last?

I believe it lasted for five or six years. In the end we had a machine that could do some things that, to our knowledge, hadn't been done before. Of course, the government didn't care much for doing robot work—whatever their reasons were, political or otherwise.

Was most of this money coming from the government?

It all came from the government. There was nobody else who would pay a nickel for this. It was all government research work, and it was all for the DoD. None of it came at that time from the National Science Foundation (NSF). When SHAKEY terminated, we kept on doing work for the DoD, but we expanded to other branches of the government, especially the NSF.

Ok, let's get back to SHAKEY. I heard that the government was not too impressed with it. I thought they pulled out their funds.

The government was probably half-impressed, half not. But they were afraid of Congress pointing their fingers and saying "what are we doing with this thing that will never go anywhere." Even though they saw things happening that they had not seen before, they knew they were not going to get a machine that would act like a full-fledged intelligent robot and do things all by itself. SHAKEY helped us realize how hard *that* was!

There was a lot of optimism in the early years of AI. Researchers insisted that intelligent machines were almost within our reach.

We didn't sell SHAKEY with that kind of optimism. We knew it would be ten or twenty years before we could build a robot with reasonable intelligence. We knew how early it was. But I don't think we felt it would take fifty years! I'd say that some of the hard problems were underestimated by factors of two to five. If you thought you could do it in five years, it'll probably take ten to twenty.

In the early years of AI, people may have expected a breakthrough—on the order of the change from vacuum tubes to semiconductors.

I would call semiconductors revolutionary. It was a "step function" that changed everything. But in artificial intelligence, everthing so far has been evolutionary. There has been no breakthrough in artificial intelligence, to my knowledge, over the whole period I've been in it. There have been small but significant steps—slow accretions of knowledge.

How did you progress from building SHAKEY to forming an industrial automation group?

About the end of the time of SHAKEY, I was getting tired of running the AI group. I had been at it a long time. By that time, I'd been watching the AI business now for quite a while. I thought the time was ripe find a piece of AI that we could use in industry. I was the only one in the AI group who had ever worked in a factory. I went through the war in a factory where, among other things, I organized a spot-welding group. Long before auto-makers did spot-welding, we spot-welded aircraft wings. Here was a chance to use some of this experience. After all, I had started my own companies, knew about production, knew about methods, and during the war I had visited over a hundred factories in the U.S. on behalf of the British.

"Even though they saw things happening that they had not seen before, they knew they were not going to get a machine that would act like a full-fledged intelligent robot and do things all by itself. SHAKEY helped us realize how hard THAT was!"

I managed to get $15,000 for six months from the Office of Naval Research (ONR), and began to tour factories around the country. As I looked around, I came to the conclusion that it was time industrial robots were upgraded. I thought they could do more than just pick-and-place a lot of stuff around. So I came back and started a group in automation.

When was this?

1971, I would guess. The president and directors at SRI backed me very heavily—to the tune of about a hundred grand. This permitted me to buy a Unimate and some other equipment—computers, cameras, and so forth. But for the group to be effective, I knew it had to be supported by industrial clients. I promoted it for the better part of the year, yet I could only find two clients. I couldn't get anybody to put even ten or fifteen grand a year into it.

But in 1971, Unimation had been around for ten years.

Oh yes! There was also Versatran—in fact, I went to Versatran. I went to Unimation. And even the robot people didn't join me at that time. I had a couple of clients who were not robot people. In the meantime, I had my Unimate built, interfaced with a computer, and beginning to do vision.

"There has been no breakthrough in artificial intelligence, to my knowledge, over the whole period I've been in it. There have been small but significant steps—slow accretions of knowledge."

About that time, the NSF started a program they called the RANN—Research Applied to National Needs. RANN was forced on NSF by Congress to a little practical, applied research to aid industry—even way back then. The NSF invited me to give a talk to a group, and I did. I gave them a big spiel, and about five to six months after that, I got a significant grant from NSF. Once again, I rewrote the program to appeal to industrial managers and engineers and put together practical demonstrations to show them it could work.

In 1971, then, it was difficult to sell advanced robotics to industry.

It was terrible. It was pulling teeth. It took me months to add each client, one company after another. We had to have those clients. You can't run a broadbased program, not only in vision, but in assembly, material handling, sensors and so forth on a hundred thousand a year—or even a quarter million a year. You have to be in the half million to million dollar class to do a proper job.

Was your goal to combine industrial robots, computers, and advanced sensors?

Yes, we wanted to bring them into integrated systems and apply them in three areas: inspection, materials handling, and assembly.

Why does industry need an outside agency? Why should they go to an SRI?

Somebody has to organize it! Let me tell you how General Motors started their robotics effort. General Motors in their research lab—and *only* in their research lab—put together a project to mount a wheel on a car using vision. And do you know the size of their effort for three years? Only two guys! GM did not have an AI group. They had a vision group composed of two people.

How about advanced manufacturing techniques and methods?

They were too busy with other things. In NC tools, other automation and tooling, they had a huge investment. But in the field of Artificial Intelligence, which includes the business of robots, they had only two workers and a few manufacturing people who were beginning to fool around with Unimate robots. Then somebody, perhaps Joe Engelberger, convinced General Motors to make an experiment at their Lordstown facility. The manufacturing technology group decided to make the experiment in spot-welding. They worked together with Unimate until they obtained a machine they liked. They put a line of spot-welding robots in, and they reworked the line until it performed. It cost a lot of money.

About that time, I gave a two hour pitch to the top people at the GM research lab and told them about this new form of automation, based on vision and AI and so forth. After my talk, I was asked: "What do you advise us to do?" I said: "Look here. I've been to Japan only once. I'll tell you what I saw." Then I told them what was happening in various places. I told them that a place like GM should build up to a group of ten to twelve people, *minimum*, in the whole field—vision oriented, AI oriented, high-level people—because you can't afford to do less. That's your threshold. And it's in the million dollar class, not in the hundred thousand dollar class. Roughly three months later, they did. GM joined our group at SRI and their research group is now very powerful. Incidentally, that research group spawned another group in manufacturing development. It's spreading. I don't know how many people are involved now in developing the PUMA for parts assembly—but it's quite a few. GE and Westinghouse followed close behind. They joined our SRI group. Now Westinghouse has committed five million dollars (a million

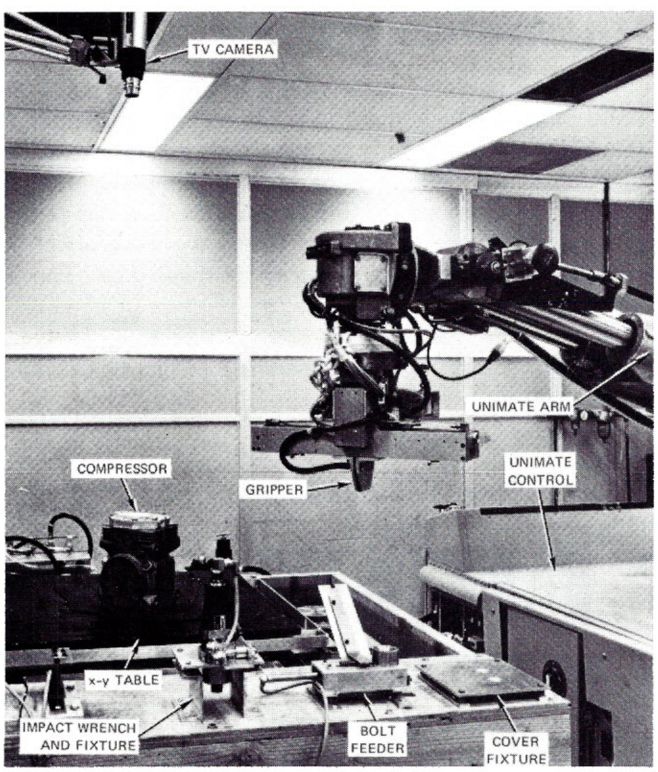
a year) to have an industrial lab at Carnegie that does nothing but advanced robots.

Is this for Westinghouse—or do they share that ?

They'll do a lot of guiding, but the university can't work for Westinghouse alone. A lot of work will be in the public domain, though some of it won't be. But the important thing is the size of Westinghouse's committment. When you get a million in one place a year you can do something!

What would you say is SRI's contribution to industrial automation?

I would say that our group was one of the most successful in putting computers, AI, robots, and sensors together. Every year, over a period of seven or eight years, we demonstrated to people that robotics could be done with means that didn't look too terribly expensive. Our group foreshadowed what was going to happen in the factories. Thousands of people have come through SRI, from all over the world, who left there saying: "We've seen the wave of the future." We succeeded in opening up eyes and thoughts and minds. At SRI we never built a finished "thing" that you could take into a factory. But we showed that it could be done.



SRI Assembly Station.

You said earlier that the SRI automation program was a combined program—both industry and government contributed.

That's right—it was sponsored by the NSF through the RANN program and aided by a significant number of high-level companies. David Nitzan, who heads the project, told me that they now have twenty-nine or thirty companies. When I left them a couple of years ago, we had around twenty companies. He has been steadily adding firms that are willing to sponsor work in conjunction with the NSF.

When you started the group, in 1970, that was not commonplace.

It was not done! As far as I know, the program that I started at SRI in automation was the first one in which someone consciously put together a combined program. And I had a hell of a time getting the industrial people to join. It took me years to get the first ten. It took personal talks and the convincing of high-level people all over the country for them to join. This was at a time when MITI* in Japan was sponsoring work that was both university and industrially cooperative. The Japanese deliberately said that they were going to develop programmed automation and went about doing it with very heavy sponsorship.

There was better cooperation between those groups in Japan than here.

Enormously better! It was mandated! In this country, most of the government and Congress felt that when robotics was applied research, it should be done by the private companies. That was their business. When it was advanced pure research that might be good for the country as a whole, then NSF was prepared to sponsor the work at universities and non-profit organizations. But NSF and private-sector efforts were kept separate. Companies didn't even want to form organizations to work with each other. They were afraid of the antitrust laws.

Is that right? It wasn't just protecting proprietary ideas?

**Editor's note: the Japanese Ministry of International Trade and Industry.*

No. Ford, General Motors, Chrysler, and General Electric would say: "If we get together to develop for ourselves a new technology, it might be construed as constraint of trade." We had to do our work in the public domain to convince the big companies that they wouldn't be sued for restraint of trade. We published everything we did with NSF grants and our client companies. It's in the public domain. Anyone can write to the National Technical Information Service and get our reports and papers.

"If the U.S. wants a robot revolution today we will not have to go to Japan to learn how to do it. The people exist in this country. We may have to get our financiers and capitalists to shell out and take some risks."

As you said earlier, Japanese industry, government, and universities have made a much stronger and more cooperative effort than the U.S. to develop programmed automation. This brings up the question on everyone's mind today: Will Japan be the strongest force in robotics in the future?

Well, first and foremost, let's look at a little history. The Japanese imported the first robot when Kawasaki made a deal with Joseph Engelberger at Unimation. To the best of my knowledge, that was the first robot that was ever made in Japan. But it was like getting a beachhead—they immediately saw what they had, and robotics bloomed. Many companies began putting robots together. There was no big secret about these robots—they were really glorified machine tools.

You're saying, then, that although robots have proliferated in Japan, these robots are not extremely sophisticated.

Exactly. The Japanese saw a good thing and they spent a lot of money and intensive effort to develop it. Yet there is no big, advanced robot system in Japan that even equals the one we created by combining the PUMA with the Machine Intelligence Corp. vision system. If it exists, I haven't seen it. It certainly has never been displayed at a trade fair. I have to point out that as far as advanced technology is concerned, in spite of the mutual efforts of the Japanese government and industry and educational institutions, working together and spending a great deal of money, the Japanese have succeeded mostly in proliferating established machines. If the U.S. wants a robot revolution today we will not have to go to Japan to learn how to do it. The people exist in this country. We may have to get our financiers and capitalists to shell out and take some risks. Only in the last two years have a few big guys—the General Motors and the General Electrics and the Westinghouses—at top management level, decided to seriously develop robotic technology.

As AI is applied in the factory, more researchers will take jobs in industry. Even now, it seems that quite a few research organizations are being raided by industry, Does that deplete the talent supply?

I think it depletes some of it. On the other hand, the universities will have more robotics courses, more people teaching, and more kids flocking to it because it will be economically good to flock to. My little company, Machine Intelligence Corporation (MIC), small as it is, has people coming who want to join us. I wish we were a rich AI company, because we'd hire a lot of these guys. They're good!

I'm glad you brought up Machine Intelligence Corpora-

tion. Tell me, how did you come to form MIC?

When I left SRI, around 1978, I was going to remain a consultant and retire. I did not intend to start a company. But a number of colleagues approached me and said: "Why not start a company, using the vision work developed at SRI?" The idea intrigued me and I said, "yes."

When you refer to vision work, do you mean the SRI algorithm?

In a way, the word "algorithm" is a misnomer. It's really a whole potful of algorithms. It's a whole potfull of methods for doing simple vision. By simple vision, I mean that you use silhouettes, black-and-white images. You spend a lot of time with lighting engineering to get a good image. You spend a lot of trouble getting a good binary image because you don't want to have to do the tremendous amount of computation you would need for gray-scale images. Ultimately, we'll be working with gray-scale images, but for now, we can do quite a bit with silhouettes. For simple vision, parts have to be aligned, fairly stable, not touching each other or waving around in the breeze. Neither the parts nor the image understanding tasks you perform on them can be too complicated. In simple vision, you recognize parts, locate them, and, perhaps, do good qualitative or semi-quantitative inspection. I felt that simple vision had arrived at a point where we could do it in the factory at a price that industry could afford. Developed over a period of three or four years, the SRI vision module, I think I can truthfully say, was the most advanced one of its kind anywhere.

Vision was your major project then.

It was a major thrust, because all other things derived from the fact that we could do vision. When we handled material, we had to use vision. When we did inspection, we had to use vision. When we had to recognize parts, we had to use vision. When we wanted to make a correction for an arm, to do assembly work or insertions, we used vision.

We also wanted to develop the vision sensor because vision is the most important sensor used by humans. We all know the reason for this: an enormous amount of useful information passes that way. So we concentrated on vision.

Of course, vision is only a part of robotics. When you talk about a language that integrates the system, that's another part of it. When you talk about a little automatic planning, that's another part. At SRI, we experimented with voice operation on the arm—that's still another important part. We used a Threshold Technology speech recognizer, a phrase recognizer, and we controlled the arm by talking to it.

When you learn to do vision, does it help you learn how to do speech? Do some of these things carry over?

Only in a very broad, abstract way. Only in this sense: you can't do advanced vision or advanced speech understanding without a great deal of knowledge about the problem domain or of the world. Facts have to be in the computer and organized in such a way that the system itself can use them. In that sense, vision and speech are similar. They're both knowledge-based systems. However, the techniques you use for extracting information from speech are different from the ones you use to extract visual features. There are abstract world-model representations common to vision and speech, but that's about it.

"...all the other things derived from the fact that we could do vision. When we handled materials, we had to use vision. When we did inspection, we had to use vision. When we had to recognize parts, we had to use vision. When we wanted to make a correction for an arm, to do assembly work or insertions, we used vision."

In any case, you selected vision as the area MIC would concentrate on.

You can't do sixteen products with a modestly funded new company. We picked vision as being the point of entry. We have other projects now going on in speech, language understanding, and expert systems. But they're very small efforts compared to the vision effort. I believe that vision is the first important result coming out of AI research that's going to work in factories.

You already made the point that vision is our most powerful sense simply because of the amount of information it processes. Now a second thing seems obvious too: we've built our world around the visual sense. So if we're going to put robots into the factories where man has worked—

Then it's wiser to use the same kind of sense. Now, I don't mean to run down tactile, force and torque sensing. Of course they're important, and we should be using them. But it's a question of relative pecking order. Tactile sensing

will increase in importance when we can make an image type of tactile sensor. It woud be like a finger tip, where you can pick up a pencil or a glass, feel it, close your eyes, and yet know what you're holding. Currently though, there is no tactile sensor equivalent to a TV camera.

How can a tactile sensor be like an image?

When I say image, I mean this: You can make a tactile sensor with many little sensors arranged in a two-dimensional array. This is analogous to a solid-state television camera which has an array of photosensors. They make this kind of tactile sensors now, but they're not very good yet. There is no tactile sensor yet that can give you touch information as well as you can get vision information. If they had an equivalent tactile sensor—let's say a hundred by a hundred matrix elements, each of which could tell the force against it—then you could begin working with the tactile sense with the same degree of sophistication as vision. But we haven't got it yet. So, in forming MIC, vision is what we chose.

"If a company says, "I want my money returned in two years with a twenty-five percent profit" before they invest in automation, I just turn my back and say: "Then you deserve what you're going to get. You're going to be another Chrysler or another U.S. Steel. You're going to get your head lopped right off." The accountants cannot run the companies forever."

We reworked, not the conceptual base of the SRI work, because that is powerful, but the practical base: How do you make a machine that's good for the factory, interfaces with the other outside world, and is human engineered to make it easy to use? It took several years of applied engineering to solve these problems and produce the VS-100, the basic vision system we're selling now. We don't see it as a finished product. We're going to keep improving it and getting new models out. In the meantime, we have a basic product that's very good for research, to try ideas out, and could be used for certain factory operations. In each case though, you have to do applications engineering. You can't just take a VS-100 to a factory and turn it loose. You have to alter parts of the factory to suit it—and vice versa—no more, no less than the first robot used to spot-weld a car body. You didn't bring a robot in and say: "weld that body," or "crank that machine tool." You have to interface the robot with the real world.

It's expensive to adapt a robot to a factory—especially the first time around.

True. Companies have to pay the extra price, heart-ache, and debugging overhead when something is automated for the first time. Later, they'll begin to see that it's profitable. In this way, spot-welding has been taken over by industrial robots. Spot-welding in car companies will never be done manually again. Automakers have found that they made the investment and it's worth it. Car painting is going to go the same way. Arc welding in a year or two is going to go the same way. These huge areas of productive capacity will soon come to robots, one by one, all of them without exception. It costs to get them going. Companies have to pay. If a company says "I want my money returned in two years with a twenty-five percent profit" before they invest in automation, I just turn my back and say: "then you deserve what you're going to get. You're going to be another Chrysler or another U.S. Steel. You're going to get your head lopped right off." The accountants cannot run the companies forever. I don't know what GM paid to put their first Lordstown spot-weld line into operation. I can assure you it was not cost effective. Not the first year, not the second year. I wish I had their numbers. It cost them a huge bundle to make that line and to put that line into conditions that robots could work in. It took them six to eight months to get it running. But they did it!

It takes a commitment from management.

It is a commitment to spend the money necessary because you're convinced that the technology is superior. The Japanese apparently are prepared to look at a five to ten or even twenty year return on investment. The Americans don't look further than a one or two year return on investment—and those little accounting words, return on investment, X percent in Y years, have cost this country more blood, more profits, and more productivity than anything I know.

How can factories start to use these tools?

Pick the simplest project where the tool could work, and make it work.

What are some good projects to start on? What should a factory manager be looking for?

Let's take the vision system we developed at MIC, as an example. A factory could start using it for inspection

projects. There are all kinds of qualitative and semi-quantitative inspection done in manufacturing. Suppose you're making pencils. Is the eraser there or did the machine miss it? Is it the right size? Want to check the color? Is it bent or broken? These are very simple things. Inspectors do look for these things. Pick something easy. Pick something that your customer would like you to have, or that will improve your yield. Start simple, and don't reckon too much on how much money you're going to make with the first one. See if you can do it, because as soon as you do it, you're going to have a hundred people in your factory looking at this and saying, "Maybe I can use this tool in *my* segment of the operation." That kind of creativity within the factory can't occur in a vacuum. You have to have a system working in that factory for the people to see it. As soon as you put a robot in that factory, people are going to say, "Hey, there are some other things we can do with that robot." But somebody has got to make the initial investment.

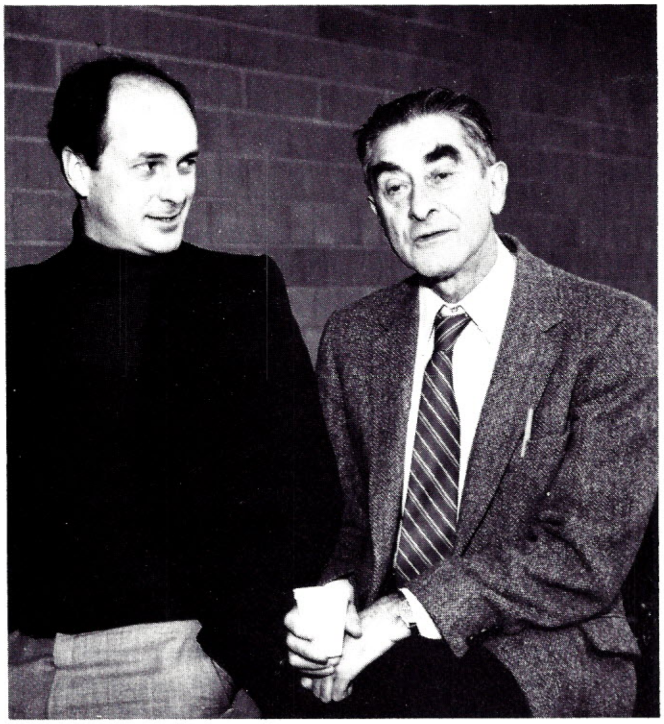
So far, we've talked about getting management to make a committment of robotics technology. But how will labor react to this new wave of automation?

It depends on their level of sophistication. Let's talk about the most sophisticated ones—the United Auto Workers (UAW), for example. If there were no such thing as competition, then they might say, "Let's be sure we never displace a single worker." But the UAW knows that if the Japanese capture 35% of the automobile market in the U.S. those cars will not be made by American workers. They also know that part of the profits made by industry has to go back into improving the productivity of the worker. They know that the only way to increase productivity without brutalizing the worker is to install new equipment that permits that worker to produce more than he did before. There is no other way. There are 100,000 UAW workers out of work today. Why? Because of Japanese and German imports and the high cost of money. The UAW is astute enough to know that both these causes can only be reversed by increasing productivity.

Therefore, the UAW says: "Let's have the new automation. Bring it on. But bring it on slowly. Don't displace a huge number of people without retraining them." The last plank in the UAW's recent agreement with the automakers effectively reduces the work week, the work year, and the number of years a worker works. They don't call it a work reduction precisely, but that's what it is. The effective work week for a UAW worker is now around 32 hours, if you count everything. He works 40 hours a week; but with extra days off, extra holidays off, extra this and extra that, the effective work week is close to 32 hours. Besides that, he doesn't have to work to 65 to get his pension. The UAW, then, is bargaining for social adjustments to head-off mass unemployment caused by new automation. They are willing to do it because the alternative is far worse.

"The Japanese apparently are prepared to look at a five to ten even twenty year return on investment. The Americans don't look further than a one or two year return on investment—and those little accounting words, return on investment, X percent in Y years, have cost this country more blood, more profits, and more productivity than anything I know."

How should we deal with the new automation? First, we shouldn't do it too quickly. You don't take a factory with a thousand people, find out how to eliminate 500 of them, and do it in a few months. You take your time because you



Charlie Rosen (right) with Industrial Editor Jerry Saveriano.

"As soon as you put a robot in that factory, people are going to say, "Hey, there are some other things we can do with that robot." But somebody has got to make the initial investment."

have to take care of those 500 people. Some will leave and go into other businesses—perhaps they'll go to the robot manufacturers, who will now have to hire people to make robots. Some will have to be retrained. You have to allow enough time in order not to displace too many people too quickly. It's unfortunately true there will always be people who can't be retrained. I am not enough of a sociologist to tell you what to do about it. I don't know the answer.

I think we are now beginning to see how people are being shifted around in industry. There are many process industries where you go into the factory and you just see a few people here and there doing their jobs; the rest is being done by machinery, and the rest of the workers are maintenance, set-up, and transfer people. You can go into hundreds of factories in the U.S. right now and see that. This is going to be the norm. Factories are going to have a fraction of the number of people in them; they're going to be just as big as they were before; and they're going to be nice and clean, with a small number of people running them. The front office is going to be automated—but because it's a lot more complicated than factory, more people will be needed to run it. You will still need sales and service people—service in the sense of managing the paperwork. Computers will never completely take that over. You're going to have a smaller reduction of people in the front office than you will in the factories. A lot of human brain work is going to go on in those offices—plotting, planning, service, sales, refurbishing, reprogramming, and so on.

Will machines eventually take over even the front office "brain work"?

AI in twenty years is not going to take over the brain work. It's going to take several hundred.

Once advanced robotic technology is proven in the factory—a controllable environment—will it then begin to penetrate the home?

Communications information processing will find its way into the home before robotics. Why? Because it's happening already, and it isn't very expensive for it to happen. Once every house has the equivalent of a good TV, which is a display device, a computer, which is a control device, and a video disk, you have access to data bases, expert systems, and educational systems immediately. Then, you will want to marry your computing power to machinery—a vacuum cleaner that you're going to tell what to do, or a window washer, or a device that brings the dishes over to the dishwasher, and unloads them. This is more expensive and harder than communications because we don't make mechanisms with a printing press; but we do mass-produce our stereos, and now, even our computers. Machines still have to be whittled out of metal and plastic and put together. It's the cost of marrying intelligence to the effectors that will hold back home robotics. But not forever.

Jerry, you're a young fellow, and you're going to see the culmination of this robot revolution. By the year 2000, there will not be any place in manufacturing that doesn't have some robotics or AI in it. Even the smallest shop will have simple machines of this kind—and all of them will have computer-based intelligence. R

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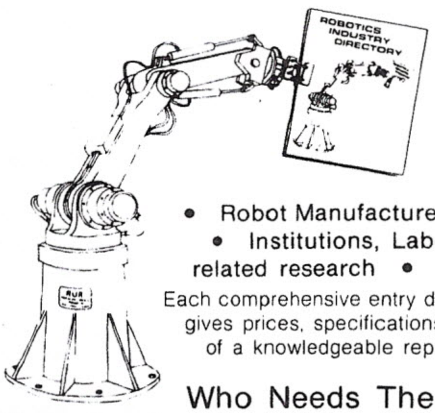

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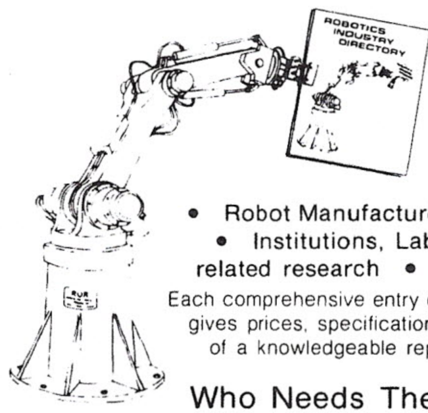
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by
Jan Rowland
Visser-Rowland Associates, Inc.
Houston, Texas

A Homebuilt Computer Controlled Lathe

Long before robots were accepted as valuable workers by industry, the use of automated machine tools had become an established practice. From the earliest *numerically controlled* (NC) machines, programmed by punched paper tape, to the latest software-programmed CNC (*computerized* NC) equipment, these tools could follow a complex cutting path, repeating it accurately and rapidly almost around the clock. In many manufacturing facilities, the use of CNC tools together with robots permit totally unmanned machining operations, where the robots load the CNC machines with raw stock and remove the finished pieces.

At first thought, it might seem that the Pipe Organ industry would be an unusual place to see automated manufacturing, since automated installations usually require a fairly high production volume to justify the large initial investment. In fact, though, since many of the parts used in organs are identical and require repetitive manufacturing steps, most of which are done by hand, opportunities for automation abound at many levels. Unfortunately, the "artistic bent" of most organbuilders is such that technology more advanced than an electric drill is ignored, for reasons ranging from simple ignorance to artistic arrogance. This appearance of *computer aided manufacturing* (CAM) in an organbuilder's shop is presently unique, although I hope this will not remain the

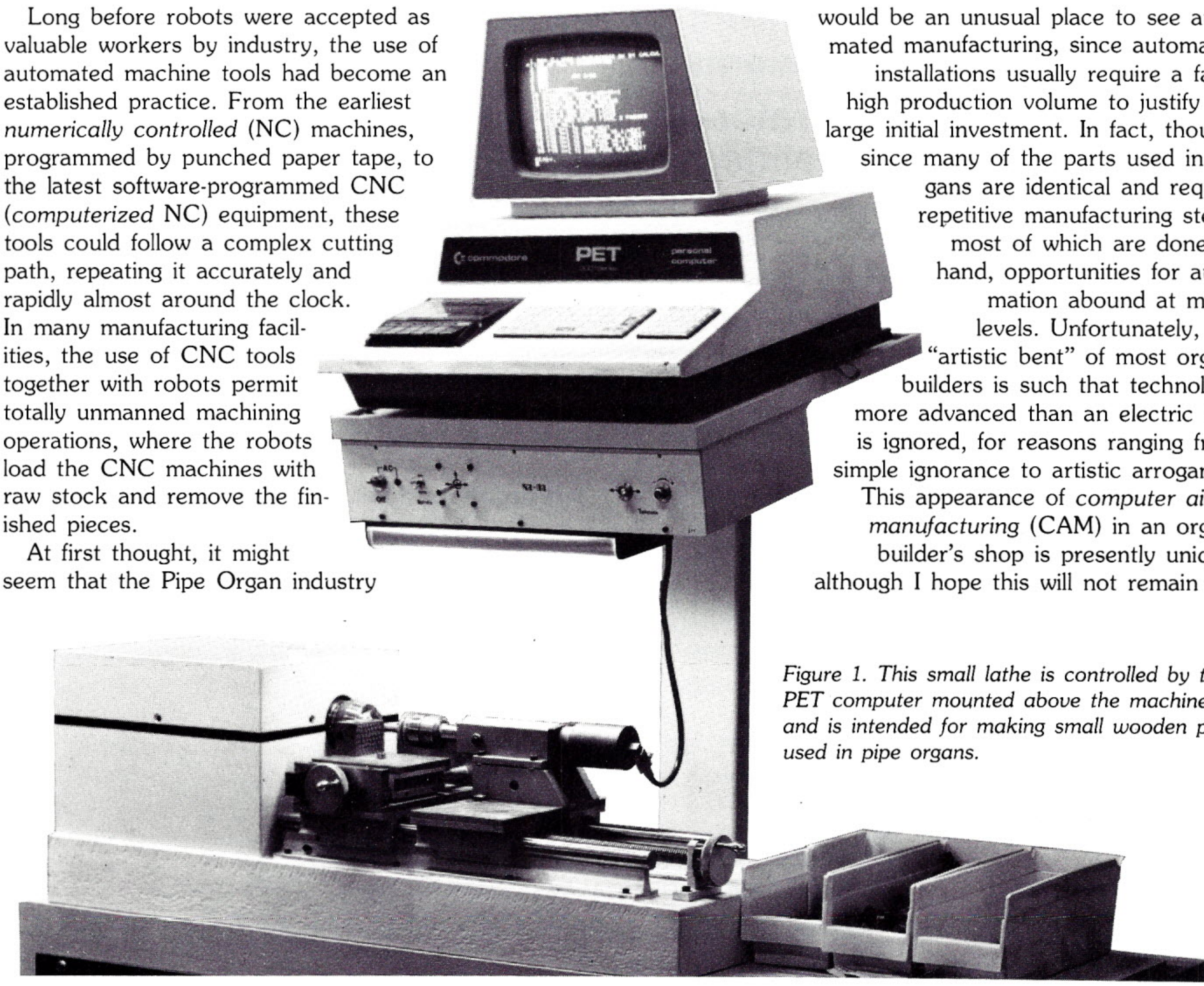


Figure 1. This small lathe is controlled by the PET computer mounted above the machine, and is intended for making small wooden parts used in pipe organs.

case for long.

One of the many parts taken for granted, but one which must be made with reasonable precision and visual attractiveness, is the "drawknob," the handle which one pulls or pushes to turn an organ stop on or off. Low-end organs have molded plastic knobs, but the trend now is for a return to the finery of instruments of the Baroque period. These older instruments, and now again half or more of the contemporary organs will have hand-turned knobs of exotic woods (ebony, rosewood, etc.). There may be any number from two to nearly a hundred such knobs on a given instrument, some quite ornate, and at prices of up to $20.00 each for hand work, the cost for these parts alone can become significant.

After hand making a few hundred for our own work, my inherent laziness inspired the construction of a small lathe fitted with stepper motors to control the X and Y lead screws, controlled by a popular hobby-computer, in this case, a Commodore "PET." Few shops in this industry can afford the $30,000 and up for CNC chuckers or lathes, particularly mine. Besides, these machines are for metal working, usually with capacities for fairly large pieces, and making organ knobs on one would be something like using nuclear weapons to kill flies. With the availability of relatively cheap microcomputers of admirable flexibility and power, other items such as stepper motors on the surplus market, and Thomson linear ball-bearings, the construction of something as ambitious as a "home-brew" CNC lathe or, for that matter, other CNC tools, is not really as ridiculous as it may seem.

There are three basic components in this machine: the lathe mechanism, the electronics other than the computer, and the computer itself. One might rightly insist that software be included in the list, but as I have so little ability with programming other than in simple BASIC, I have managed to do all I ever intended (and all the machine itself is capable of!) without the use of any special software other than self-explanatory BASIC programs which control the machine directly in real-time, using the POKE command for communication to "the outside world" from the computer. Therefore, I leave "software" off the list, and leave sophisticated machine code programming to the more sophisticated reader.

The Lathe Mechanism

As can be seen from the photographs, the linear track, or "ways," of the lathe are standard case-hardened shafting (by Thomson Industries), mounted on a base of ordinary steel channel. Leveling the rough surface of this base or chassis would ideally be done by surface-grinding, but this would have cost at least a hundred dollars alone. Trick #1: Drill and tap the base for one of the shaft-support's mounting screws, smear a liberal coat of fast-hardening epoxy on the bottom of the support rail, then immediately screw it down to the base, making the screws just snug. Wipe away the excess epoxy which may squeeze out, and after it hardens, tighten the screws. What has happened is that the epoxy has filled in all the voids between the bottom of the shaft-support rail and the rough channel, making a very firm and level interface. Now, assuming you have already made the lathe saddle (or carriage or whatever, depending upon your specific application), it can be used as a "gauge" to locate the second shaft precisely on the base. Again use the epoxy trick, this time *before* any drilling. It might be necessary to level the second shaft to match the plane of the first by using shims. Run the carriage back and forth to insure that the two shafts are parallel, and let the epoxy harden. Now you can drill, tap and bolt the second shaft support down. While this procedure might make a professional machinist nauseous, it works. The adhesive qualities of the epoxy are unimportant since it is being used only for "grout" or filler.

The *carriage*, which supports the lateral axis of the cutting tool, and the *tail-stock*, which holds the free end of the workpiece, are both made with Thomson linear bearings, the basic idea being quite clear in the photographs. Since the precision is built into these ready-to-use pillow-blocks and shafts, it is possible to all but avoid the need for professional machine-shop operations. A drill

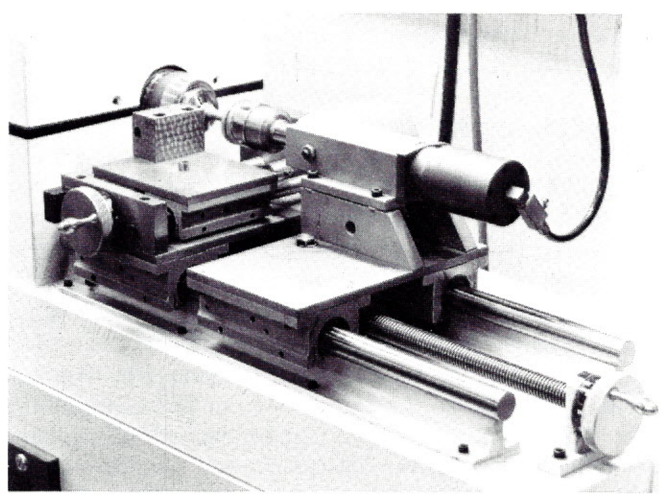


Figure 2. Closeup of the lathe mechanism. The tailstock center is operated pneumatically, maintaining continuous force against the workpiece, in this case by means of a cup-center.

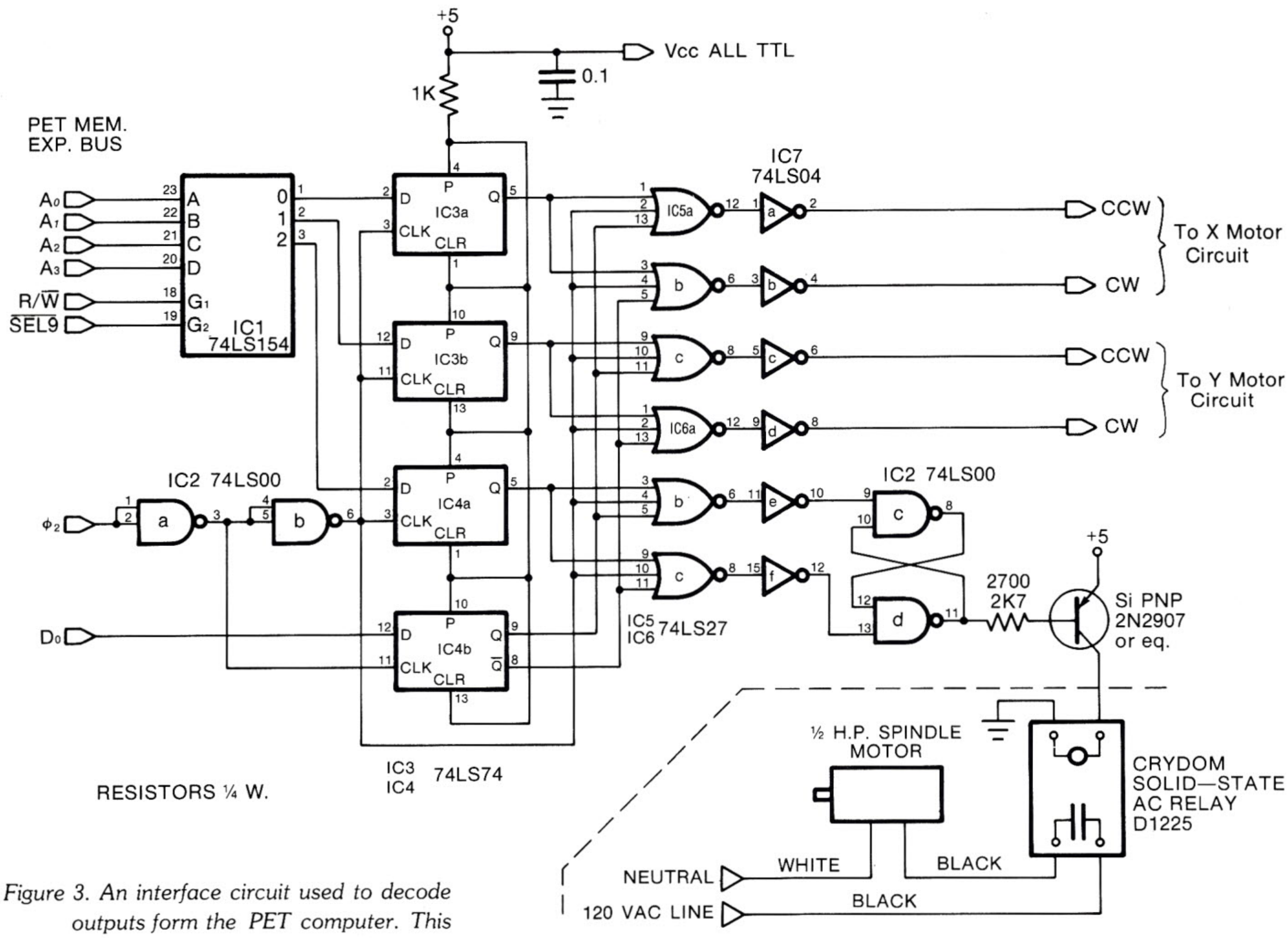


Figure 3. An interface circuit used to decode outputs form the PET computer. This circuit also controls the spindle motor.

press should be all one requires to do a passable job for all parts.

The lead screws, believe it or not, are replacement parts from a Whirlpool trash compactor. These screws in that particular make are ⅝″ diameter ACME threads, and the nuts which transfer the force to the mechanism in that machine are "split," consisting of two identical mating halves. This makes it possible to squeeze the two halves together by means of a spring in a suitable holder so that there is no play, ideal for the lathe application, or anywhere else where reasonably accurate position is needed, with fair forces involved. I merely sawed off appropriate lengths of the threaded portion of the screw shafts and performed very minor machining in an ordinary engine lathe to adapt the ends for my use. Alignment of a pair of bearings for a shaft such as these screws can be difficult, particularly when this shaft must be axial with a motor. But the stepper motors themselves have fine ball bearings, and I used the motor shaft as one support for the respective lead screw, leaving only one bearing to worry about. I used simple Oilite type bushings, as the speed is relatively slow, and these can be reamed after installation for free operation—this is not possible with precision ball bearings.

The lathe spindle is an Atlas 12″ lathe spindle. This choice was made for several reasons. First, the cost of the part is far less than a custom-made spindle. Second, standard lathe chucks and collets can be fitted directly to it. This spindle was mounted in standard Boston Gear flange bearing blocks, the self-aligning type with spherical outer races. The spindle drive motor is a very ordinary and inexpensive 3450 RPM tool motor, Nr. 48 frame. It is connected to the spindle by sheaves (V-pulleys) and a V-belt. Ordinary cast zinc sheaves are not made with adequate precision for this speed, so I made both from chunks of scrap in the engine lathe. This was particularly necessary on the spindle, since the I.D. was 1½″, and no small sheaves have such a large bore, and cannot be reamed due to the shape of the castings. I should stress that at speeds over 2000 RPM, the precision of the V-belt drive sheaves must be very good, or considerable vibration will result. In fact, I was able to later reduce the vibration I encountered (in spite of all steps to prevent it initially) by

trimming the motor sheave *after* its installation on the motor shaft. Placing the motor in the engine lathe between centers (with the lathe turned off) made the V-groove in the sheave perfectly concentric with the motor axis, running the motor itself provided the turning power for the cutting.

I can now see that another approach would be preferable, though it would require some expensive professional machining. If I had to do it over again, I would modify a standard motor by replacing its shaft and bearings with the lathe spindle itself, and suitably larger bearings. This would mean considerable work on the motor end plates, if not replacement with specially made ones. But the elimination of the V-belt drive and separate bearings would have made it worth it. This way, the motor itself would become the lathe's headstock. In any case, the machine is built and intended to run at only one spindle speed: 3450 RPM, ideal for woodworking and some plastics turning.

Controlling the Lathe

The lead screw drive system used on the lathe has more in common with general robotic methods. There are basically two ways to move a mechanism to a specific position upon command from a computer or other controller:, a servo system with feedback (closed loop) and stepper motors with no feedback (open loop). In the first system, the computer compares the desired position with that measured by the feedback system, typically potentiometers or shaft encoders of some sort. The direction and speed of the servo motor, whether electrical, pneumatic, or hydraulic, is determined by the computer, based upon this comparison, and information is sent to the servo motor to control it to perform the desired movement. For machine-tool precision, this system is usually far more expensive and complex than the second method, the stepper motor system. A stepper motor is a specialized DC motor which rotates in discrete angular increments (steps) upon command from its associated drive circuitry, usually manufactured and supplied by the same manufacturer as the motor itself.

All stepper motors are poly-phase devices. That is, the several windings in the motor are controlled by separate switches which sequence the current in these windings in some specific order of phase-related pulses. If certain windings are switched on and others off, the motor will step. If the sequence is repeated, the motor will step again in the same direction, and if the order of the pulse sequence is reversed, the motor will step in the reverse direction. If the "rules" are obeyed—the proper rate and sequence observed—the motor shaft will always rotate a specified amount. However, if the stepper motor is stalled by some outside force, such as an obstruction in the mechanism connected to it, it will not "catch up" after removal of the problem, since the pulses sent to it during the stalled condition are lost forever. Here, the servo system with feedback has an advantage, since the feedback element will continuously inform the computer or other controller what movement is actually occurring (or *not* occurring). Thus, once any problem is removed, the servo system will immediately attempt to catch up to where it should have been had there been no obstruction. In the present application, however, since the movement of the lathe carriage is relatively small, and since obstructions and such problems can be readily controlled, nothing more sophisticated than the familiar stepper motor drives are necessary.

In this application, the stepper motors are Superior Electric type MO 92 or HS 50, the latter being the older version of the same type, which I was able to locate on the surplus market for less than half the price of the new version. These have considerable average torque and 200 steps per revolution. Thus, with a lead screw pitch of 10 to the inch, the travel per pulse is 0.0005", a relatively fine resolution for a woodworking machine! Superior Electric manufactures an extensive line of solid state translators and preset indexers for their several types and sizes of stepper motors. The simplest of these is capable of up to 1000 steps per second, which converts to about 300 RPM. This STM-101 circuit board with connector sells for $100, and seems to be based upon early '60's technology—the flip-flops are constructed with discrete transistors, diodes, and capacitors! Figure 4 is a schematic of a stepper driver circuit which will perform easily as well, and can be built for much less. A great deal of energy must necessarily be wasted as heat in the two ballast resistors in series with the return leads form the motor windings due to complex electrical inductive actions at various speeds. The full details of this behavior are beyond the scope of this discussion and can be studied in Superior Electric literature and engineering guides.

The drives for both the *X* and *Y* axes are of course identical, and each has two inputs, one for forward and one for reverse (CCW and CW or "UP" and "DOWN" count). In order for the computer to control the driver circuits, an interface must be constructed which will decode the outputs from the computer and route them to the appropriate axis and direction. This interface for the Commodore PET computer is shown in Figure 3. It is interesting to note that somewhat simpler interface

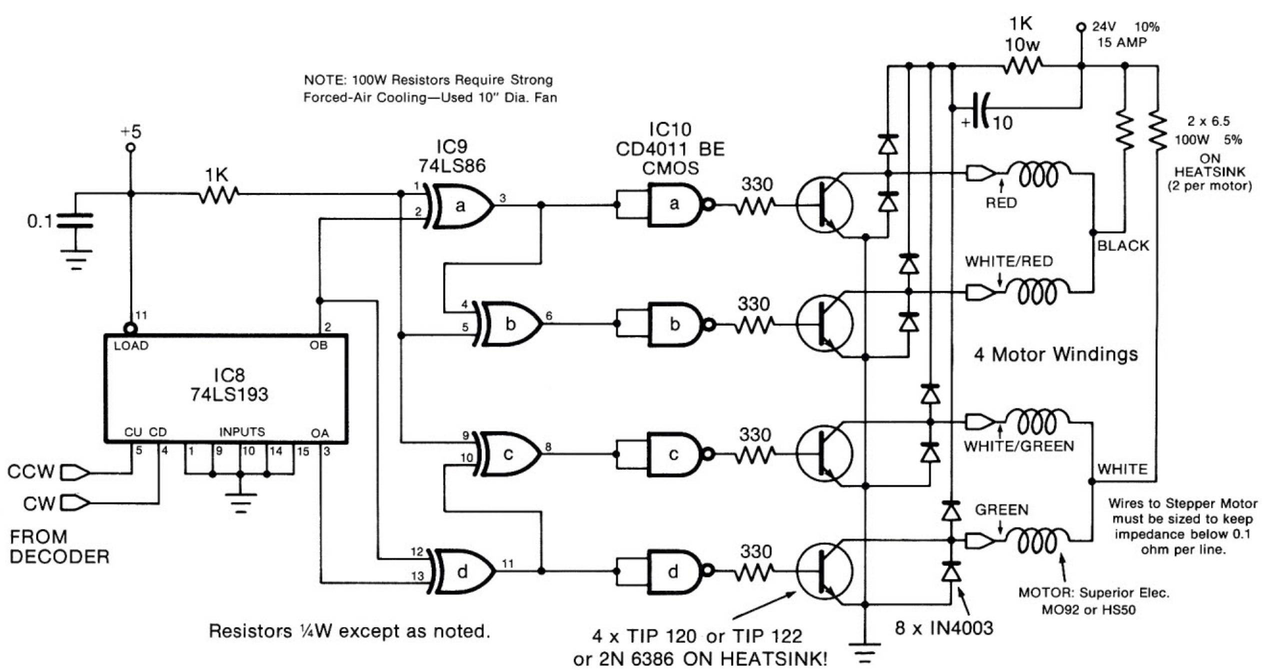
circuitry is possible for use with either machine code or BASIC "POKE" commands, but not both. For some reason I do not quite understand, the machine code "STA" command, which puts a byte into a particular address, has different timing than whatever MPU operation does this job whenever the "POKE" command is used in the high-level language, BASIC. But the interface shown will accept either type of manipulation, as it latches the address and data at different points on the clock cycle. This detail is undoubtedly different for other makes of computers, and the logical sense of the address select lines (if any) may be positive instead of negative as it is with the PET. But this basic circuit should work with other popular types of personal microcomputers with little or no modification. Note that the decoding of the addresses is not really complete, and a number of individual addresses will be decoded identically, although all will lie within the $9000-9FFF range. I use decimal 36864 for the *X* axis, 36865 for the *Y* axis, and 36866 for the spindle motor switch. Any byte in which the LSB is "1" (an odd number) will cause a forward pulse, and any byte in which the LSB is "0" will cause a reverse pulse. For example, if you enter the command "POKE 36864,1" the *X* axis motor will move one step forward. In a BASIC program, the following line

```
100 FOR I=1 to 1000:POKE 36864,1:NEXT
```

will cause the *X* axis to move exactly ½". It is best to assign the values to legitimate variable names, e.g., "LET XA=36864," as this will run faster and result in less typing in a program.

Backing up a bit, the spindle motor is switched on and off by means of a commercial solid state AC relay, this one being a CRYDOM (International Rectifier) D1225, able to switch up to 25 amps of 120 V AC. The controlling input to this type of relay is any DC voltage from 3 to 32 V DC, so a normal TTL signal will control the motor. A short delay

Figure 4. A suggested stepper motor translator/driver circuit. This circuit will drive small and medium sized stepper motors to rates up to 1000 steps per second. The driver transistors should be mounted on insulated heat sinks of at least 8 sq. in. area per device. The 100 watt ballast resistors should be mounted on a large heatsink with strong forced-air cooling. Regulation on the 24 volt supply is not critical.



Some Sources for Hard-to-Find Mechanical Parts

It is amazing how quickly a tinkerer's imagination can dream up new and clever ideas once sources for weird and hard-to-find parts become available, particularly when the catalogs from the suppliers contain good drawings of the parts offered and suggestions for their use. There are many manufacturers of precision gears, sprockets, dials, bearings, pawls, ratchets, shafting, motors, and so on which are potentially useful in the type of mechanical movements found in robotic devices. But there are relatively few single sources for many of these parts. You'd be surprised how few professional designers are aware of some of the best sources.

Often, custom parts that are made at great cost could have been found "off-the-shelf" in a precision mechanical components catalog. The availability of some standard parts should inspire slight changes in designs on paper, allowing the use of standard parts instead of custom items.

The Winfred M. Berg, Inc. firm (449 Ocean Ave., East Rockaway, L.I., NY 11518) is one of the best sources for small precision components and assemblies. They offer by return mail a free catalog, that contains not only detailed drawings of the parts offered in thousands of sizes and types, but a number of design ideas as well. A competitor, the PIC Design division of the Wells Benrus Co., (6842 Van Nuys Blvd., Van Nuys, CA 91405, phone 213/782-6702, with additional offices in the Benrus Center, Box 335, Ridgefield, CT 06877, phone 203/431-1500) also has many small precision parts. Both companies offer parts in metric measure.

Stock Drive Products (55 South Denton Ave., New Hyde Park, NY 11040) offers more small mechanical components, but leans toward timing-belt parts. They also have a line of small DC motors with and without gearboxes.

It is fair to point out that the pricing of the precision parts offered by the above firms may shock the neophyte, but you must realize that the cost is in the precision—few of these parts are "stamped out." Most are machined on very expensive semi-automatic equipment that must be amortized. For precision movements, be prepared to pay a price!

Surplus sales firms offer some items at comfortable prices. But the disadvantage in dealing with a surplus firm is that they offer only what they have on hand at any given time, and often it is impossible to get replacement parts or any quantity. You can find some excellent companies handling surplus and new items in most major cities. Some good examples are C&H Sales Co. (2176 E. Colorado Blvd., Pasadena, CA 91107), AST/Servo Systems, Inc. (930 Broadway, Newark, NJ 07104), and H&R, Inc. (401 E. Erie Ave., Philadelphia, PA 19134). These firms offer both new items in unopened packages (from bankruptcies, etc.), and used items, ranging in condition from nearly worthless to virtually new. Items may be sold on an "as is" basis or with some sort of guarantee; and this is usually indicated in their catalogs. They offer such things as stepper motors, DC servo motors, encoders, gauges, tools, instruments, and many other types of miscellaneous items. They have nice catalogs with photographs of the items offered.

Heavier gears and bearings are available from Boston Gear Dvision of Rockwell International (14 Hayward St., Quincy, MA 02171). Boston also supplies standard sprocket chain and gears in a huge range of sizes. They publish an extensive catalog, again with drawings and explanations, engineering charts, etc.

W.W. Grainger, Inc. (5959 Howard St., Chicago, IL 60648) has distributors in most cities throughout the United States. They offer many different types of industrial motors in the fractional and integral horsepower sizes, and all sorts of industrial equipment—even some domestic items. For the robotics enthusiast, they also offer some small gear motors, which are very reasonably priced, and a few fractional horsepower DC drive motors. The latter might be useful for wheel-drives on larger robots since they can be controlled in much the same way as slightly more sophisticated DC servo motors. The best thing about Grainger, aside from their large line of products, is that their prices range from very low to reasonable, and their service and availability of offered items is good to excellent. "Check Grainger's first" is a good motto for any shop, whether for hobby or heavy industry!

There are a number of makers of stepper motors and controls. Some specialize in very small types—of the kind used in computer printers, others in military versions. Superior Electric Co. (383 Middle St., Bristol, CT 06010) is one of the best known firms making stepper motors, and the line they build appears in many types of commercial robots, machine tools, and office machines. Superior's line of stepper motors range from roughly 25 oz-in of torque up to one or two horsepower. They also manufacture solid state translators and indexers for their motors. Their catalogs contain torque-vs.-rate charts for all types with all controllers which might be compatible, as well as some engineering data. They also publish a small handbook about stepper motors and the AC Slo-Syn motors they also make. This booklet tells how to match or select a motor to a given load and whether the drive system uses belt, pulley, or lead screw. Formulas are given for each case, and step-by-step examples are included.

While it is true that large population centers are the best areas in which to find the type of items mentioned above, it

may surprise you how much can be found in isolated places. The Yellow Pages is one of the best "catalogs" a designer can possess, and should be one of the first places to look—in conjunction with the telephone, of course—before giving up.

For those interested in the source of the spindle used in the lathe, the best and most direct source is, believe it or not, Sears. The spindle is Sears part number 10-31T for the model 101.28980 lathe. You can order it as a replacement part. It is actually manufactured by Clausing, a large and well-known machine tool manufacturer. Atlas is a subsidiary of that firm. Sears offers the Atlas lathe with the Craftsman brand pasted over the Atlas name. The spindle nose is internally a standard No. 3 Morse taper, and the outer diameter is 1.5-8 threads. Therefore, you can fit it with standard chucks and collet devices of many brands, available from any machine tool supplier.

Jan Rowland

loop in the program must be entered after the motor is turned on via "POKE MA,1" (MA is the Motor Address of 36866 decimal) to allow the spindle to come up to speed.

Describing the Cutting Path

Since memory is limited, the storing of points along the shape of the desired part to be turned is not a good idea for the drawknob turning application, since there are often many curves, difficult to express in terms of a series of Cartesian coordinates. Instead, I write the programs as a series of one or more mathematical functions such as expressions for circles ($R*R=X*X+Y*Y$, for example), ellipses, etc. Straight line paths are, of course, easiest. The individual Y values along the X axis are computed separately, and the new step count is the algebraic difference between the old Y and the newly computed Y value. This value is used in a FOR-NEXT loop, POKEing a 1 or 0 as many times as appropriate. But this calculation requires quite a lot of time in BASIC, and if the Y value for every single step in X were calculated, a typical organ drawknob could take as much as an hour to make! By taking 10 steps in X between Y movements, the cutting rate is speeded up tenfold, and the reduced resolution is no problem due to the nature of the parts being made—they are usually sanded right in the lathe and later polished with compound. Clearly, clever machine language coding would speed things up considerably, but stepper motors are cantankerous and must be *accelerated* to step rates over 400 steps per second (this depends upon many mechanical variables, so one must usually make actual performance tests to determine acceleration and deceleration requirements). If any faster computer output is to be contemplated, special self-decrementing delay loops to insure correct acceleration must be provided. This can become quite involved, and I feel very lucky that the CBM BASIC running in my machine is just the right speed to permit direct, acceleration-independent running of the stepper motors without loss of position. In other words, I can write lines such as this

```
100 FOR I=1 TO 1000:POKE XA,1:NEXT
200 FOR I=1 TO 1000:POKE XA,0:NEXT
```

and the carriage will move ½" to the right, instantly reverse, move ½" to the left and stop, with a dial-indicator showing a very precise return to the starting point. In a robotic mechanism using stepper motor drives with no form of feedback, careful consideration must be given to this acceleration problem. In some computer-controlled stepper motor devices with software provided to run on popular computers, the acceleration details are embedded in the software, and are "transparent" to the user.

In my original design, I included a simple joy-stick (operating only contacts, not pots) to make it easier to set the carriage at a desired starting location during initial set-up. This control invokes local oscillators which ramp up to speed and run much faster than the computer can output its pulses. I have found that this device is not as useful as I thought it might be, and I have deliberately omitted the circuit details from the schematics. Simple is better, and one can easily enter direct-mode commands on the CRT and use the screen cursor control keys to affect direct movement of the carriage. Once set up for a run, no further human intervention is necessary in the operation of the lathe other than replacing a finished part with a new blank, and pressing the RETURN key, since the tool bit always returns to the starting point after finishing work—that is, if the program is written correctly!

It now remains for me to build a true robot to stand before this lathe and exchange the finished parts with prepared blanks, as is done in heavy industry. Speaking of pipe-dreams... R

For sources of parts used in the CNC lathe, see the accompanying item, "Some Sources for the Hard-to-Find Mechanical Parts."

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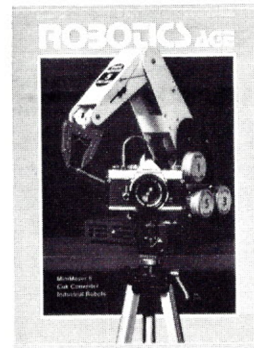

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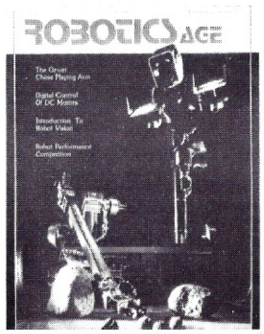

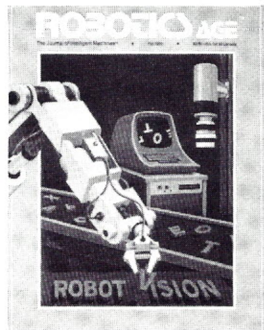

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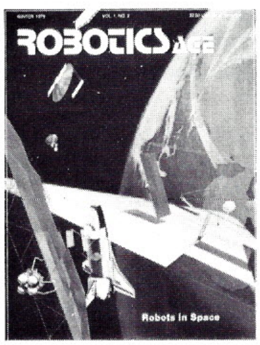

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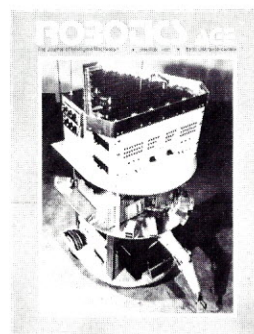

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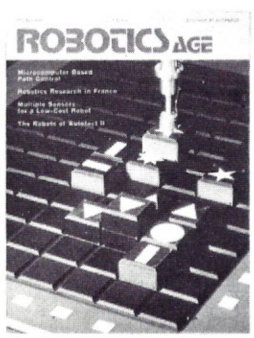

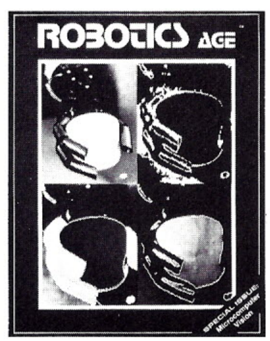

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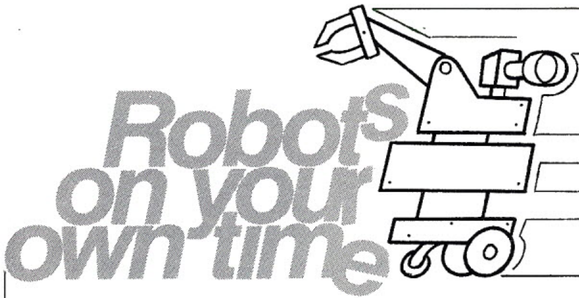

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Rolling Hills Estates, CA 90274

SUPERKIM MEETS ET-2

PART II: SENSORS

In "SUPERKIM Meets ET-2" (*Robotics Age, Fall 1980*), I described how I interfaced and programmed a SUPERKIM single board computer (SBC) to control the Lour Control ET-2 robot shell.

Without sensors, though, the SUPERKIM/ET-2 combination described in that article is not a true robot, since all of its movements are "open loop," that is, without feedback. This article describes how to interface contact sensors and sensors that require A-to-D conversion (such as infrared scanners or temperature sensors) to the SUPERKIM/ET-2. Once you interface the contact sensors furnished with ET-2, you can program avoidance behavior. This permits the SUPERKIM/ET-2 to sense when it has contacted an obstacle, and take appropriate avoidance actions. I refer the reader to the Fall 1980 article for details concerning motion control of the ET-2 by the SUPERKIM.

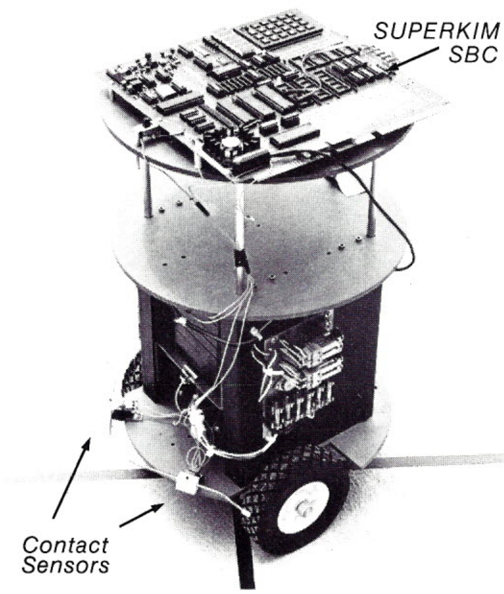


Figure 1. Contact sensors can be mounted around the base of ET-2.

Interfacing ET-2 Contact Sensors to the SUPERKIM

ET-2 provides a number of contact sensor switches that can easily be interfaced to the SUPERKIM. These contact sensors, equipped with metal "feelers," can be mounted around the base of the ET-2 to sense contact with an obstacle by means of a switch closure.

Lour Control has provided four independent contact bumper assemblies, which are designed to ring around the base of ET-2 as shown in Figure 2. Whenever a guard rod, which projects out of either side of the assembly, comes in contact with an object during ET-2's motion, it is deflected laterally, activating a built-in momentary switch. Depending on which way the switch is toggled, and on the control program in SUPERKIM, the ET-2 can then perform an avoidance manuever.

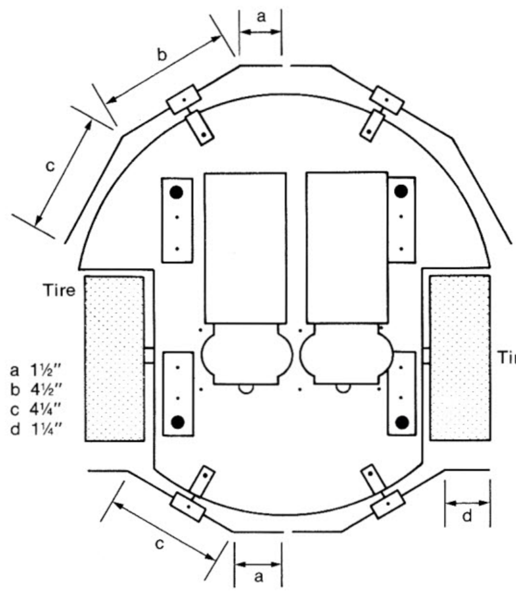


Figure 2. Location of contact switch/bumper assemblies.

As figure 3 shows, each of the bumper switches have four basic parts—the guard rod, connecting block, switch, and mounting bracket. The guard is a 5/32 inch diameter rod that protrudes from both sides of the connecting block and acts as an extension of the switch's own toggle lever. You can easily distinguish the two bumper assemblies installed in the front section of the shell, since their guard rods are shorter than those mounted in the rear section. The switch's toggle lever and the guard rod are both attached to the connecting block by means of set screws. The switch itself is a momentary, on-off-on device that automatically returns to the center (off) position when released. A spring wire, wrapped around the switch's mounting stud, holds the connecting block in a horizontal position and aids in the resetting of the switch. The entire unit is attached to one of the four mounting holes on the tier of ET-2 by means of a corner angle mounting bracket.

Table 1

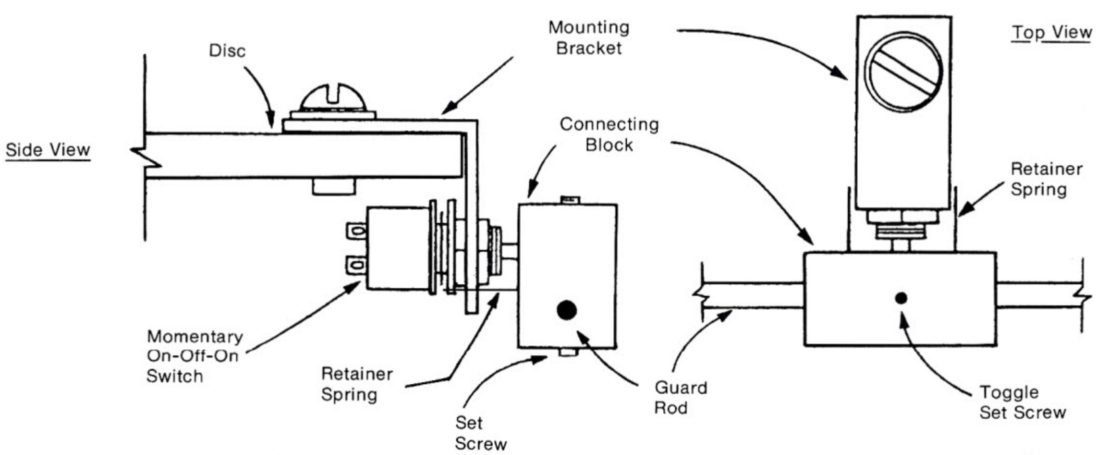
Connector Jack J2 (U11) 6530-003 I/O

Pin 0	=	Ground
Pin 1	=	PA0
Pin 2	=	PA1
Pin 3	=	PA2
Pin 4	=	PA3
Pin 5	=	PA4
Pin 6	=	PA5
Pin 7	=	PA6
Pin 8	=	PA7

We used SUPERKIM's 6522 to interface the SBC with ET-2's motor and relay controls. SUPERKIM also comes with two 6530 ROM/interface ICs, designated 002 and 003. To interface these sensors to SUPERKIM, we must first consider the operation of the I/O ports in a 6530. Each 6530 array provides 15 I/O pins. The microprocessor and operating program define whether a given pin is an input pin or output pin, determine what data are to appear on the output pins, and read the data appearing on the input pins. The I/O pins provided on 6530-002 are dedicated to interfacing with specific elements of the KIM-1 system, including the keyboard, display, TTY interface circuit, and cassette tape interface.

The I/O pins on the 6530-003 (U11) are brought out to connector jacks J2 and J3, and are available for user applications. Connector jack J2 has 8 pins constituting Port A, as shown in Table 1. Connector jack J3 has 5 pins constituting Port B, as shown in Table 2. Pin 0 on Port A is a ground line. Pins 1 through 8 on Port A and pins 1 through 5 on Port B are the programmable I/O lines. Figure 4 shows the location of the pins on the 6530-003 connectors J2 and J3 that are used as contact sensor input lines.

Figure 3. Contact sensor assembly (detail).



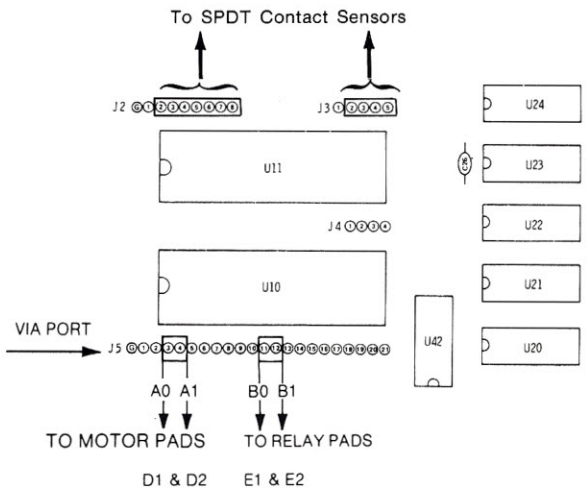


Figure 4. SUPERKIM/ET-2 contact sensor interface connections.

Each of the lines shown in Figure 4 go to one end of the desired (SPDT) contact sensor, as shown in Figure 5. Since the central pole of the switch is connected to ground, as the switch is opened and closed, the corresponding pin on jack J2 or J3 will be either an open circuit (corresponding to logic 1) or grounded (corresponding to logic 0). Read the data registers for Port A from memory location 1700H and the data registers for Port B from memory location 1702H.

You can interface the touch sensors by connecting one side of the SPDT switches mounted around the base of the ET-2 to signal ground and the other side to the appropriate pins of Port A and Port B. To understand how this connection works, consider the partial state diagram of the data register shown in Table 3.

If any of the pins PA1 through PA8 are connected to ground, then the corresponding state of the data line is set to zero, as shown in Table 3. The data byte stored in memory location 1700H—and read out by the KIM display—is the hexadecimal equivalent of the binary number represented by the states of the signals on PA1 through PA8, with PA1 being the least significant bit (LSB) and PA8 being the most significant bit (MSB). Thus, Port A alone can handle some 2^8=256 on-off contact sensor states.

Table 2

Connector Jack J3 (U11) 6530-003 I/O

Pin 1	=	PB0
Pin 2	=	PB1
Pin 3	=	PB2
Pin 4	=	PB3
Pin 5	=	PB4

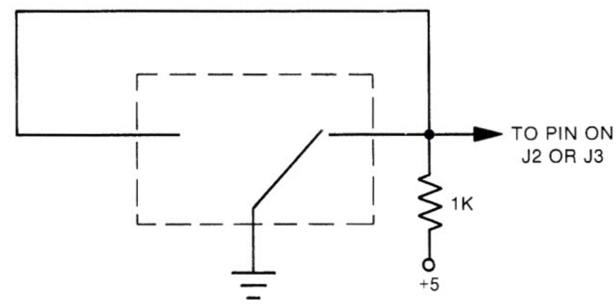


Figure 5. Contact sensor connection.

Motion Commands Based on Contact Sensor Data

The SUPERKIM can use contact sensor data to initiate a sequence of avoidance maneuvers any time the robot comes into contact with an obstacle. This behavior can be very complex, since a different avoidance maneuver routine can be triggered for every possible combination of contact sensor output. When all 8 contact sensors are mounted around the base of ET-2, the robot might use as many as 256 different avoidance maneuvers.

The principles behind this can be illustrated by considering two touch sensors on the front of ET-2, both wired to PA1 of Port A. In this case, KIM gets data byte FE if either front sensor contacts an obstacle. Table 4 gives a simple program making use of this data in a closed-loop fashion.

Execution of the program in Table 4 allows the SUPERKIM/ET-2 combination to go exploring somewhat in the manner of a billiard ball. The ET-2 moves forward in a stop-and-go fashion until one of the two forward contact sensors touch an obstacle. When this happens, the avoidance routine is called, which rotates SUPERKIM/ET-2 until the touch sensors are no longer in contact. Then the robot resumes its forward stop-and-go motion. Figure 6 shows the path of SUPERKIM/ET-2 under control of this program.

Table 3

Data Byte Equivalent of Port A Sensor Signals

Address	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	DATA BYTE
1700H									
	1	1	1	1	1	1	1	1	FF
	0	1	1	1	1	1	1	1	FE
	1	0	1	1	1	1	1	1	FD
	1	1	0	1	1	1	1	1	FB
1 = Open	1	1	1	0	1	1	1	1	F7
0 = Grounded (closed)	1	1	1	1	0	1	1	1	EF
	1	1	1	1	1	0	1	1	DF
	1	1	1	1	1	1	0	1	BF
	1	1	1	1	1	1	1	0	7F

As figure 6 shows, the path of ET-2 looks something like the trajectory of a billiard ball. By changing the program's delay constants at 0300H, 0311H and 0313H, you can change the angle of rotation of ET-2 during the avoidance manuever, as well as the duration of the start and stop motions.

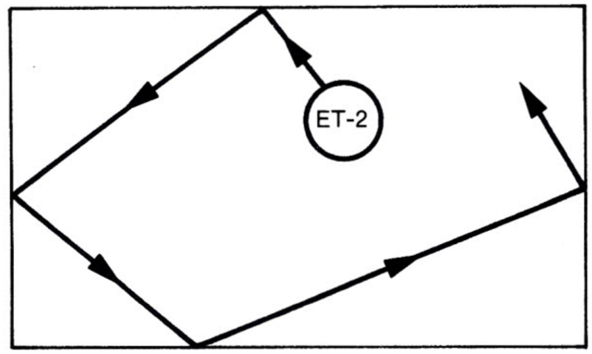


Figure 6. Path of ET-2 under control of the SUPERKIM "Billiard Ball" program.

Interfacing Analog Sensors to ET-2

Besides interfacing ET-2's contact (touch) sensors to the 6530 I/O parts you can also interface sensors that require analog to digital conversion (A/D). Sensors require A/D conversion when their output is a continuously variable signal or voltage as opposed to the 1 or 0 binary output of a touch sensor. Examples of such sensors useful in robotics are force/pressure transducers, temperature sensors, infrared sensors, or potentiometers used for shaft angle feedback in computerized servo control.

An LSI circuit, the ADC0817, is the primary IC in a 16 channel 8 bit A/D converter (ADC) system, which you can attach to the bus of the SUPERKIM 6502.* This ADC chip provides a relatively fast (100 microsecond) conversion time. Once the conversion has begun, the CPU can work on other tasks until the digital result is available.

The ADC0817 appears to the program as a block of memory starting at a base address, BASE, and extending through 16 locations to BASE + 15. (The actual circuit described occupies 4000 locations because of incomplete decoding which you can remedy if desired.) A conversion of a selected channel, say channel X, is started by writing to BASE + X. The 8 bit conversion result may then by read from any location in the block (eg. BASE) any time after the 100μs conversion time has elapsed. If you need multiple A/D conversions at the maximum speed, you can keep the 6502 busy with "housekeeping" during the conversion delay time. The system uses just five integrated circuits. The design, shown in Figure 7, occupies six square inches on the SUPERKIM prototype area, and draws only 60 mA of current from the 5 Volt DC power supply.

Operation of the circuit is simple because the ADC0817 performs all analog switching and A/D functions. The microprocessor R/W and $\phi 1$ lines, along with an inverted board select signal, are combined in two NOR gates, which 1) latch channel select bits A3-A0 and start A/D conversion during $\phi 1$ write cycles, and 2) enable the tri-state data bus drivers during $\phi 1$ read cycles.

You may want to take advantage of the SUPERKIM's interrupt circuitry to allow your program to go on to other tasks after starting the A/D conversion. The ADC0817 produces an end of conversion (EOC) signal when the most recent conversion has been completed. You can connect the EOC to a processor interrupt line (such as pin

Table 4

"Billiard Ball" Program Listing

Address	Contents	Label	Operation	Comments
0200	A9 03	Loop:	LDA #$03	;Polygon Program
0202	8D 03 13		STA $1303	;Turn Relays Off
0205	A9 00		LDA #$00	
0207	8D 02 13		STA $1302	;Both Motors On
020A	20 00 03		JSR LDELAY	;Wait
020D	A9 03		LDA #$ 03	
020F	8D 02 13		STA $1302	;Both Motors Off
0212	20 00 03		JSR LDELAY	;Wait
0215	AD 00 17		LDA $1700	;Check Contact Sensor
0218	49 FE		EOR	;Compare with FE
021A	FO 03		BEQ (Z=1)	;Avoidance if FE
021D	4C 00 20		JMP LOOP	;Keep On Going
0220	A9 01	Avoidance:	LDA #$01	
0222	8D 03 13		STA $1303	;Right Relay On
0225	A9 00		LDA#$00	
0227	8D 02 13		STA $1302	;Both Motors On
023A	20 00 03		JSR LDELAY	;Wait
023D	A9 03		LDA #$03	
023F	8D 03 13		STA $1303	;Turn Relays Off
0242	A9 03		LDA #$03	
0244	8D 02 13		STA $1302	;Both Motors Off
0247	20 00 03		JSR LDELAY	;Wait
024A	60		RTS	;Loop:
0300	A0 01	LDELAY:	LDY #$01	;Set Default Count
0302	8C 20 03	LOOP1:	STY COUNT	;Save It
0305	20 10 03		JSR SDELAY	;Call Short Delay
0308	AC 20 03		LDY COUNT	;Get Count
030B	88		DEY	;Count Down 1
030C	D0 F4		BNE LOOP1	;Continue Til Zero
030E	60		RTS	;Return
0310	A2 FF	SDELAY:	LDX #$FF	;Outer Constant
0312	A0 FF	LOOP2:	LDY #$FF	;Inner Constant
0314	88	LOOP3:	DEY	;Inner Countdown
0315	D0 FD		BNE LOOP3	;Loop Until Zero
0317	CA		DEX	;Outer Countdown
0318	D0 F8		BNE LOOP2	;Loop Until Zero
031A	60		RTS	;Return From Subroutine
0320	00		COUNT: (Long	Delay Count Hold Location)
			END	

*Both Texas Instruments and National Semiconductor produce the ADC0817.

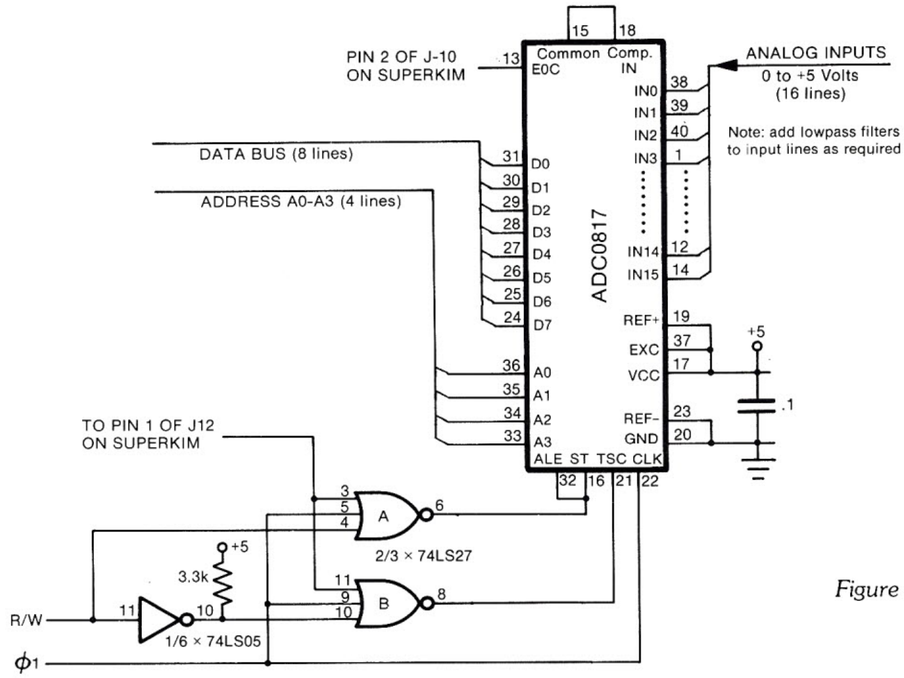


Figure 7. 16 channel analog-to-digital converter system.

2 of connecter J-10) through one of the 74LS05 open collector inverters. These interrupts can only be cleared by starting another A/D conversion. To use the interrupt feature, you must write additional software to initialize the processor interrupt and to "handle" the interrupt when EOC occurs.

Wire-wrap construction is suitable for the circuit—and component layout is not critical. It is good practice, however, to orient the analog input area away from digital circuits. The ADC circuit has two limitations: 1) analog input voltages must be between 0 and +5 Volts, and 2) the signals being converted should not change appreciably during the 100 μs conversion period.

Table 5 depicts subroutine MCAD for multi-channel A-to-D conversion without using interrupts, along with an example of a calling routine for MCAD.

The program which calls the A-to-D conversion subroutine must initialize both the channel selection and storage-defining parameters before the JSR instruction is executed. In the program given, the channel selection information is contained in an index register for ease of use in starting a conversion.

Table 5

A-to-D Conversion Routine

```
0200           BASE  *      $B000  ;BASE ADDRESS OF ADC0817
0200           STORE *      $9000  ;START OF 16 BYTE STORAGE
                                           AREA
0200 9D 00 B0  MCAD  STAX   BASE   ;START CONVERSION ON
                                           CHANNEL X
0203 A0 0E           LDYIM  $0E    ;DELAY FOR CONVERSION
0205 88        DY    DEY           ;MINIMUM VALUE = $0E
0206 D0 FD           BNE    DY
0208 AD 00 80        LDA    BASE   ;GET CONVERTED DATA
020B 9D 00 90        STAX   STORE  ;STORE DATA
020E CA              DEX
020F 10 EF           BPL    MCAD   ;DO NEXT CHANNEL
0211 60              RTS           ;FINISHED
```

Example Calling Routine for MCAS

```
0212 A2 0F     MCMAIN LDXIM $0E    ;SELECT CONVERSION OF ALL
0214 20 00 02         JSR   MCAD   ;16 CHANNELS AND GO TO
                                   ;SUBROUTINE
0217 00               BRK          ;EXIT ** BE SURE TO INIT IRQ
                                   ;VECTOR**
```

Conclusions

The SUPERKIM controlled ET-2 robot is an excellent, moderately priced system to which the robotics experimenter can easily add more sensors and other equipment.

The contact sensors provided with the ET-2 leave something to be desired in that they do not make contact with overhanging obstacles such as tables and chairs. They do work adequately with vertical walls, and can be used to demonstrate obstacle avoidance behaviour in a suitably prepared environment. R

References

[1] D. F. McAllister, "SUPERKIM Meets ET-2," *Robotics Age*, Fall 1980.

[2] "Instructions for SUPERKIM," Lamar Instruments, 2107 Artesia Blvd., Redondo Beach, Calif. 90278.

[3] "ET-2 Assembly Manual," Lour Control, 1822 Largo Crt., Schaumberger, Illinois 60194.

Eye to Industry

by J. W. Saveriano

American robot-makers are turning their nervous eyes towards Japan. Last year, in his *Robotics in Japan* report, Paul Aron of Daiwa Securities estimated that Japanese industry has about half of the world's computer-controlled robots. In 1980, Japan produced more robots than the total number installed in the U.S. This February, *Business Week* warned that Japanese robot-builders were establishing "beachheads in the U.S." With this in mind, I present a few *Newsnotes* from Japan.

Hitachi Corporation announced in March that they will put 500 people (in six laboratories and seventeen factories) to work on the development of intelligent robots. Hitachi, Japan's largest manufacturer, is determined to reduce manual labor in assembly operations by 60 to 70% over the next five years. Hitachi's robots will be mobile and have vision and tactile sensing. Once proven in their factories, Hitachi will market the robots world-wide.

Nippon Electric Corporation (NEC) announced recently that they have developed a super-precision assembly robot. Called the "Arms-D" robot, it uses linear motors as actuators and 16 sensors to control its motion. It can handle four pounds at a speed of 45 cm/sec with repeatability of ±8 *microns* (.008 mm). More than 15 of these robots are already working, each at three times the speed and five times the productivity of humans. The robots will be applied mostly in the assembly of hybrid integrated circuits, multi-contact switches, printed wire boards, and so on. NEC expects to market the "Arms-D" robot by 1982.

Also adding to Japan's new wave of robots is **Toyota Motors Corporation**. The "T-10 Project" consists of 10 companies belonging to the Toyota corporate family. They plan to develop a medium-sized robot for the assembly of automobile parts and components. They intend to compete with Unimation's Puma 500 robot. Toyota hopes to be producing a thousand of these robots per month by 1985 and to sell them at a target price of $25,000 each. I've heard rumors that **Panasonic** of Japan has also built robots to assemble electronic components. The same source also mentioned that Panasonic is building an ASEA-type manipulator to compete with the Hitachi and Yaskawa electric drive welding robots.

Let's turn from Hitachi to the American company that uses Hitachi manipulators in their robot welding systems. **Automatix**, the Crosby, Stills, Nash and Young of robotics, has decided to use the **Lincoln** welding power supply as the standard for their robot welding systems.

Meanwhile, back in California, I attended several interesting meetings on robotics in the last few weeks. **Robotics International**, Chapter 250 of Southern California, had a meeting that covered Artificial Intelligence, Man/Machine Interfaces and "Disposable Robots." The meeting was held at **Perceptronics** in Woodland Hills, California, and conducted by Dr. Amos Freedy of Perceptronics and Dr. John Lyman, of UCLA. Both Freedy and Lyman specialize in developing products that employ artificial intelligence techniques.

Their products usually keep a human in the control loop—as in the teleoperated underwater manipulator they built for the U.S. Navy. The manipulator controller is computer-assisted and capable of certain levels of semi-autonomous operation. Because they designed the arm to work in a constantly changing environment—unlike a factory—an operator uses cameras to watch and help guide the manipulator through its task. This work emphasizes the sharing of intelligent decisions between man and machine to accomplish the task.

Also at the meeting was Dr. Efram Shaket of **Tetrax Corporation**, a consultant group that also works in applied artificial intelligence. Dr. Shaket discussed a man/machine-oriented language called TOSC (*Task Oriented, Sentence structured Command Language*). TOSC was designed to simplify the interaction and communication between man and machine.

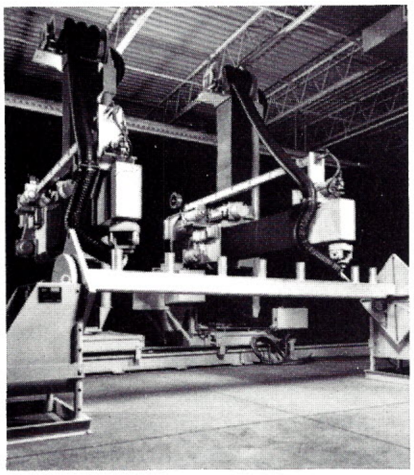
Finally, Dr. Freedy talked about a new project that was begun by **Perceptronics** for the government—"Disposable Robots." These are robotic machines, contained in three spherical pods, that could be dropped by parachute into a dangerous area, such as a contaminated nuclear or chemical plant. Two of the pods would contain worker-robots and the third, the control pod, would contain a human supervisor. The two worker robots would enter the facility and discover and repair the damage with help from the control pod. After completion of the mission, the control pod would be picked up and the worker-robots would be left behind. The worker-robots would therefore do dangerous "use once and abandon" work. These machines would be of special design, and would have few similarities to their factory cousins.

Be seeing you!

If you have robotics-related information that you believe is noteworthy, or have suggestions for topics for this column, please write us at *Eye to Industry*, **Robotics Age**, PO Box 725, La Canada, California 91011, or call 213/352-7937.

NEW PRODUCTS

Two Meter Welding Robot



Advanced Robotics Corporation has just announced the introduction of its new Cyro™ II arc welding robot. According to a company spokesperson, Cyro II was designed for arc welding of large components normally fabricated by manufacturers of construction equipment, rail cars, tractors, trucks, military vehicles, earthmoving equipment, farm machinery, coal mining equipment, ship fabrication and other large fabrications.

Cyro II is a five axis robot. The main axis provides a working volume of 2 meters × 2 meters × 2 meters. The wrist rotation is 720° and the wrist tilt is 140°. Cyro II's horizontal travel axis has an unlimited expansion potential to accommodate even larger parts or multiple work stations.

Also available from ARC are part-positioning robots whose operation can be directed by the same controller. Multiple welding and part-positioning robots can all be integrated into the Cyro control for smooth, continuous interaction. Welding process components can also be integrated to provide total computer control over process parameters. The units can also be equipped with a fume recovery system and a device to automatically clip the welding wire and clean the torch.

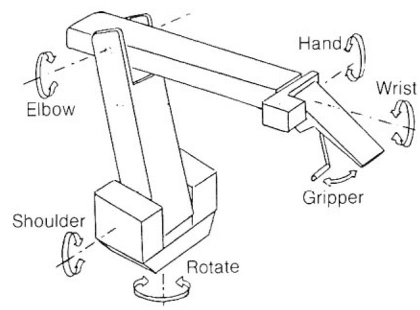
The Cyro II can be equipped with an AFT™ adaptive control. While running a rough program, a mounted probe tracks the weld joint, determining its actual path, and relays the information to the Cyro control unit, which automatically modifies the stored path to track the seam. Where physical intrusion of the probe prevents total access, the Cyro control suspends tracking and extrapolates the projected path. Contact Advanced Robotics Corp., Bldg. 8, Newark Ohio Ind. Park, Hebron, OH 43025. **CIRCLE 1**

Servo-Controlled Miniature Manipulator

Smart-Arms is a complete miniature robot arm for use in education and research, which can be controlled by a microcomputer using a high-level command language. Two versions are available: a 4 motion unit (shoulder, elbow, and azimuth rotation plus gripper—20cm max. reach), and a larger 6 motion version that adds wrist and hand joints (roll and pitch—30cm max. reach). Each joint is driven by a miniature servo motor.

Smart-Arms includes an interface board that can drive up to 8 servos and can have up to 3 input and 3 output 8 bit ports. The I/O ports are used for process sensing and control. Options for latching ports and miniature relays are available.

Software written in BASIC (source included) is provided that enables the user to command any of six different movement modes: move directly to position, move through

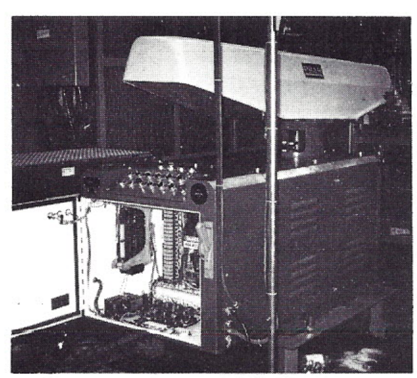


intermediate steps, perform a relative sub-motion, test input ports, search a path until sensor signal, search—but record position where sensor signal occurred.

Interfaces and software are available for the Commodore PET, Acorn ATOM, and Sinclair ZX80. For other computers, please inquire. For price and delivery, contact B. A. Robinson, Systems Control, 15 Westbourne Rd., Linthorpe, Middlesbrough, Cleveland, England TS5 5BN. Phone: (0642)88716. **CIRCLE 2**

Prab Robots Now Obey Other Controllers

Robot users may choose a new controller option when purchasing a robot from Prab Conveyors. The new option allows a Prab robot customer to supply or specify his choice of programmable controller



(PC) to be mounted inside the robot's control panel or remote-mounted with an interconnecting cable.

In many cases, according to Prab, a customer may already have installed a series of controllers in his plant to run other machinery. Prab provides the option to continue using a PC that his staff already knows how to operate and maintain.

PCs offer better synchronization between robots and other automation. They have the ability to coordinate and monitor several machines within one work cell with branching and decision-making routines. They can communicate with other PC's as well as with computers, enabling the configuration of hierarchial control systems.

Prab already has installed a considerable number of customer-supplied and specified programmable controllers using this new option, including PCs by Reliance Electric, Intel, and others.

Customarily, a drum memory control runs the Prab robots.

Contact Prab Conveyors, Inc. Joan M. Juzwiak, 5944 E. Kilgore Rd., Kalamazoo, MI 49003, 616/349-8761. **CIRCLE 3**

High-Resolution Optical Position Detector

The OP-EYE system can detect the location of an image on its 1cm ×

1cm detector surface with a resolution of over 1 part in 4000. Using a two-axis lateral effect photodiode, the centroid location of a bright spot on the detector surface is obtained via four analog signals from the edges of the detector. These are amplified and digitized in a 12 bit A/D converter (16 bit optional). The unit is complete with an interface that stores the results in four pairs of memory locations in an Apple II computer. Location sampling rate is over 5kHz.

The complete system, including the detector, 16 channel A/D converter and Apple II interface, preamplifiers for two detectors, 28mm camera lens, programming manual and related equipment, costs $1550 for a 12 bit system and $1995 for a 16 bit system. An extra detector and lens assembly for 3-D applications is $365. Contact United Detector Technology, 3939 Landmark St., Culver City, CA 90230, 213/204-2250. **CIRCLE 4**

Phonetic Speech Synthesis For LPC Systems

Using TI's "Speak and Spell™" as an output device, Speak Up Software gives your computer not only the ability to speak, but also (in a fashion), the musical qualities of song (which you can hear on a demonstration cassette). While you may not really be interested in making your home computer sing, Speak Up gives you independent control of pitch and voice. This allows you complete control over intonation and voice pitch.

The method of speech generation in the Speak Up system is phonetic speech sysnthesis. This means you type in ASCII symbols corresponding to the sounds of speech. To make the computer say "Speak" you simply type in S.PEE.K on your keyboard.

Speak Up Software does not now sell any hardware for this system. In addition to the commonly available TI "Speak and Spell" (about $60), you need an interface to connect it to your microcomputer. A 6502 to "Speak and Spell" interface can be obtained from East Coast Micro Products, 1307 Beltram Court, Odenton, MD 21113 (about $60).

These companies supply the necessary hardware to allow your Speak Up Software to generate phonetically synthesized speech.

If you're interested in hearing phonetic speech by LPC synthesis, send $4.95 for the demonstration cassette. Programs are currently available for 6502 systems and in the near future for the TRS-80. Updates will be published on the TRS-80 program status.

The phonemic driver software is available for $14.95 from Speak Up Software, 3491 River Way, San Antonio, TX 78230. **CIRCLE 5**

Voice Control Unit Recognizes 40 Words

A subsystem developed by Auricle, Inc. can be trained to identify one of up to 40 different isolated words or short phrases spoken by a human operator. During the pause following an utterance, the Auricle-I compares a statistical description of the utterance with stored descriptions of the machine's vocabulary. The vocabulary is defined during a training session in which the operator speaks each word or short (up to 1.2 sec.) phrase three times so that the machine can derive "typical" statistics for each item. Recognition accuracy is

claimed to be 99%. The unit has a RS-232 interface to communicate digital codes for each recognized word to a host computer.

The unit's vocabulary is expandable to 168 words or phrases. The Auricle-1 costs $2480, and the company, whose parent firm is Threshold Technology, Inc., expects to have a single-board OEM version available later this year. Auricle, Inc., Cupertino, CA 95014, 408/257-9830. **CIRCLE 6**

Type-'N-Talk™ From Votrax

VOTRAX®, a pioneer in electronic speech synthesis, is introducing its new Type-'N-Talk™ text-to-speech synthesizer that allows a hobbyist's personal computer to talk back to him in highly intelligible English words and phrases.

Used in conjunction with any computer that has an RS-232C interface, Type-'N-Talk™ permits the hobbyist to type an unlimited combination of English words and phrases on the keyboard. The computer will then "speak" the words typed. Words can be spoken simultaneously as they are typed, or Type-'N-Talk™'s 750 character buffer will hold the words until the user prompts the computer to speak them in entire phrases or sentences.

Typewritten words are automatically translated into electronic speech by Type-'N-Talk™'s microprocessor-based text-to-speech algorithm. The verbal response consists of electronic-generated phonetic speech which is heard through the user's audio loudspeaker. The system can also display phonetic codes which the user may optionally store in the host computer's memory. Even the smallest computer can execute programs and speech simultaneously because Type-'N-Talk™ does not require the use of a host computer's memory to produce speech.

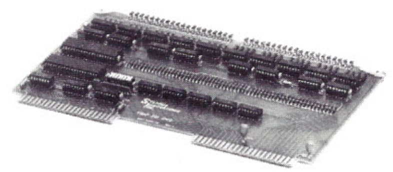
VOTRAX® is selling its new Type-'N-Talk™ speech synthesizer for $345 per unit. Orders may be placed through VODEX, the national distributor for VOTRAX®'s specialized speech synthesizer products. Contact: Russell F. Thielman, General Mgr., VODEX—A VOTRAX® Co., 500 Stephenson Hwy., Troy, MI 48084, 313/588-0341. **CIRCLE 7**

Hybrid D/A Converters

Datel-Intersil introduces a new family of high performance hybrid 12 bit digital to analog converters. The DACs allow a choice of voltage or current output models with either 12 bit binary or 3 digit BCD coding in commercial, industrial, or military operating temperature ranges.

All models provide voltage output settling times of 3 μsec maximum and current output settling times of only 300 nsec maximum. Digital inputs of the CAC-685/687 series are both TTL and CMOS compatible, with digital input current of only 10 μA. Voltage outputs are pin programmable with ranges of 0 to +5V, 0 to +10V, ±2.5V, ±5V and ±10V. Current output models have pin programmable outputs of 0 to −2 mA and ±1mA for binary coded versions and 0 to −1.25 mA for BCD versions. Datel-Intersil, 11 Cabot Blvd., Mansfield, MA 02048, 617/339-9341. **CIRCLE 8**

Optically Isolated I/O Boards



Systems Innovations, Inc. has added two optically isolated I/O boards for use in its VIμP Series systems (Versatile Industrial Microprocessor) and with other "KIM 4" bus compatible microprocessor systems (AIM, SYM, etc.).

The D40 and D40H Modules provide 20 output channels and 20 input channels with 1500 volt optical isolation; four of which have interrupt capability. Four 16 bit timer/counters are provided.

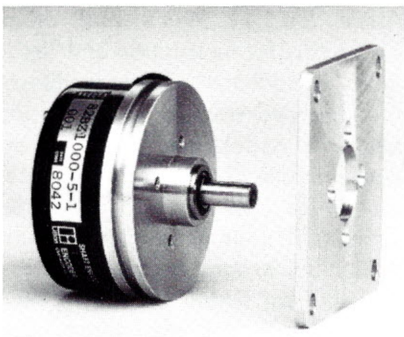
An additional feature is the use of one visible LED for each channel in addition to the coupling LED's, thus providing a visual indication of the status of each channel at the board level.

Output drivers are open collector transistors with a common emitter bus. Two power output versions are available; the D40 with 150 mA. output and the D40H with Darlington Drivers capable of 1/2 Amp output. Maximum standoff voltage for both versions is 40 volts.

The D40 and D40H are factory

stock and are priced at under $300 in OEM quantities. For further information contact: Systems Innovations, Inc., PO Box 2066, Lowell, MA 01851, 617/459-4449.
CIRCLE 9

Housed Optical Encoder From Litton



The Model 82 Incremental Shaft Position Encoder provides an inexpensive means of sensing rotary speed or position in space restrictive environments. The Model 82 is a 2.2 inch diameter by 1.25 inch high optical incremental encoder. Precision ball bearings and TTL electronic compatible outputs are used in the unit, along with the highly reliable solid-state Gallium Arsenide illumination sources. Standard units provide two quadrature channels for determining direction. A zero index third channel is also an option, as well as +5, +12, +15, or +24 volt operation. Twenty-four standard resolutions are available up to 1024 cycles, while other resolutions, from 1 to 2540 cycles, can be provided on special order. The standard round frame is also available with a square flange mount.

Typical applications include machine tool position readouts, test and calibration equipment, robots, and a variety of control systems. Contact: Marlene Votion, Litton Encoder Div., 20745 Nordhoff St., Chatsworth, CA 91311, 213/341-6161, ext. 192. **CIRCLE 10**

5V Regulator Features Low Dropout Voltage

National's new LM330 offers the lowest dropout voltage of any fixed regulator on the market: 0.32V at 150mA. Instead of requiring 7.0V to operate, the LM330 provides a 5.0V ouput from input voltages as low as 5.32V. This results in much longer useful life from batteries and greater system efficiency. Designers may use lower battery voltges (e.g. 6V), and note that heatsink requirements are greatly reduced. National Semiconductor, Inc., 2900 Semiconductor Dr., Santa Clara, CA 95051, 408/737-5000. **CIRCLE 11**

STD Prototyping Boards

Bob Mullen offers a trio of prototyping boards for the STD bus. Each is .0625″ FR-4 glass epoxy with .038″ plated through holes (.025″ square pins) on a .1″ grid. The boards have solder plate over 1 oz. copper and have 30 micro inch gold on connector surfaces.

The STD-001 has a 56 by 41 grid and is spaced to allow connectors for flat cable up to 50 conductors.

The STD-002 has a 53 by 41 grid and a 36 position (dual 18) edge connector. It comes with a short card ejector to allow clearance for a hooded connector.

The STD-003 has a 51 by 41 grid and a 16 position terminal strip capable of handling 15 amps and 300 volts. The terminal strip is UL recognized and has its metal parts enclosed. Single conductors can be added or removed and the entire terminal strip can be removed from the board without disturbing the existing connections. The terminals are corrosion resistant, have a wire guard to prevent damage, and will handle up to 16 AWG wire.

Prices: Quantity 1-3, STD-001 $29, STD-002 $34, STD-003 $39. For further information contact Bob Mullen, 2306 American Ave., #6, Hayward, CA 415/783-2866.
CIRCLE 12

Motor Control Chip

A new IC, Plessy's TDA1085, protects motors and triacs against damage caused by servo loop failure or electrical overloads. The chip works with either digital or analog shaft speed feedback, and provides gradual acceleration. Current limiting occurs if the motor stalls, and the TDA1085 senses feedback loss and prevents motor runaway. With its own on-chip regulator, the device accepts either AC or DC input power. Contact Plessy Semiconductor, Inc., 1641 Kaiser Ave., Irvine, CA 92714, 714/540-9979. **CIRCLE 13**

ORGANIZATIONS

Octek Forms Systems Group

Octek, Inc., of Burlington, MA, has recently formed a Robot Vision-Special Systems Group under the direction of David King. The group will incorporate the Company's vision modules in turnkey systems used for industrial applications in automated measurement, sorting, inspection and robot vision.

SME Plans New Directory To Guide University Research

The Society of Manufacturing Engineers is preparing a new directory, listing the manufacturing research needs of industry. This 3rd edition of SME's **Directory of Research Needed by Industry** is intended to help university researchers identify those manufacturing areas requiring immediate research and development efforts and to help government and other sponsoring organizations direct their R&D funds more effectively.

Directory co-editor Dr. Richard L. Kegg of Cincinnati Milacron, Inc., said the new compilation will prove mutually beneficial to students and industry. "Our directory will give students a wide variety of choices to consider for thier research theses and provide them with contacts in industry. It will help industry by bringing some of its most pressing problems to the attention of people who are qualified to shed light on them." Completion date for the directory is scheduled for December, 1981.

Directory editors have sent questionnaires to nearly 2,000 industry representatives asking for a description of current problems in need of new solutions. Others in industry wishing to submit a manufacturing project for listing in the directory should provide the following information: A—Description of the problem, B—Background (things tried already), C—Estimate of economic importance, D—What people in what industries will put the results to immediate use? E—Suggestions for research approach, F—Name and address of person to contact for more details.

Send contributions to Dr. Richard L. Kegg, Technology Development Dept., Cincinnati Milacron, Inc., 4701 Marburg Ave., Cincinnati, Ohio 45209, or to Dr. Neal P. Jeffries, Center for Manufacturing Technology, 4170 Crossgate Dr., Crossgate Square, Cincinnati, Ohio 45236.

Computer Camp Adds Robot

A robot will join the campers at this summer's Computer Camp. Instructors will use this mechanical mascot as a teaching aide to demonstrate the application of robots in today's industries and tomorrow's homes. The robot will be available for the campers to play with, program and learn from throughout the summer.

Computer Camp will start on July 5, 1981 with four two-week sessions. Camp will be held this summer at Zaca Lake, about 40 miles north of Santa Barbara. The camp is nestled in the Los Padres National Forest amid forests of redwoods, pines, and oaks. Campers will stay in log cabins that rest on the shores of the lake and all food will be prepared by Zaca Lake's Chef.

There will be a ratio of one computer per two campers, with campers receiving three hours of computer instruction per day. The campers will have ATARI 800's, Apple II's, TI 99/4's and other computers for instruction and "free-time." In addition to the three hours of scheduled training, campers will have the opportunity to spend an equal amount of computer "free-time" for games and personal projects. The elementary curriculum will include programming computers in PILOT and BASIC languages, how to both write and play games with computers, and films about how computers work and what they are capable of doing. For the advanced campers there will be discussions on logic, artificial intelligence, floppy disks, color graphics, computer generated speech and music, robotics, computer chess, and programming in the LISP and PASCAL languages.

For further details, contact Gary White, Director, Computer Camp, Inc., 1235 Coast Village Rd., Ste. G, Santa Barbara, CA 93108, 805/965-7777.

RI/SME Names Six New Board Directors

Robotics International of the Society of Manufacturing Engineers (RI/SME) has announced the appointment of six new members to its Board of Directors.

The six are: Harry E. Richter, Industry Consultant, IBM Corporation, White Plains, New

York; William H. Blaisdell, Assist. Director, Management Services Div., Eastman Kodak Company, Rochester, New York; Joseph F. Engelberger, President, Unimation, Inc., Danbury, Connecticut; L. J. Hudspeth, Vice President, Corporate Productivity, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania; Thomas D. Mathues, Vice President, Manufacturing Staff, General Motors Corporation, Warren, Michigan; and Richard C. Messinger, Vice President, Research, Cincinnati Milacron Inc., Cincinnati, Ohio.

Founded in March, 1980, RI/SME now has 15 chapters in the U.S. and Canada and has a current membership of 2,400.

For additional information about RI/SME, contact Ms. Toni Miller, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48128, 313/271-1500, ext. 416.

Calendar

The 1st International Conference on **Automated Guided Vehicle Systems,** June 2-4, 1981, Stratford-upon-Avon, UK, provides a unique opportunity to learn how AGVS systems are helping to increase productivity in many different industries.

There are now more than 1000 AGVS systems installed in the USA alone. Internationally recognized experts will describe how to justify AGVS systems (payback less than 3 years) and how to cut costs and boost productivity both in materials handling operations as well as in storage and retrieval.

More intelligent AGVS systems are now being developed worldwide, improving their guidance and control capability. These aspects will also be highlighted at this conference.

For further information contact: IFS (Conferences) Ltd., 35-39 High St., Kempston, Bedford MK42 7BT, England, tel: Bedford (0234) 853605 & 855271.

International Motorcon Conference and Exhibition, June 10-13, 1981, Conrad Hilton Hotel, Chicago, Illinois. The world's biggest conference on electric motors and their controls will feature two major position-speeches by key military and industrial spokesmen on energy saving motor strategies for the 80's, and the military's newly-developed techniques for motors and controls in energy-critical space borne applications.

Motorcon '81 will feature over 30 technical sessions, and panel discussions and futorials covering all aspects of semiconductor control of AC, DC, and step motors, as well as a special application session on factory automation and robotics.

For more information, contact Mr. Earl Nickel, Program Coordinator, at 805/985-1595 or write MOTORCON '81, PO Box 2889, Oxnard, California 93034.

Previously Announced:
Refer to the original Robotics Age *Calendar announcement for details.*

SME Clinics, Robots: Management Overview Clinic, Denver, CO, June 16-18. Contact SME, 1 SME Dr., PO Box 930, Dearborn, MI 48128, 313/271-1500. Announced in Vol. 2, No. 3.

1981 Joint Automatic Conference, June 17-19, 1981, U. Virginia, Charlottesville. Contact: Prof. James W. Moore, Dept. of Mech. and Aero. Eng., U. VA, Charlottesville, VA 22901, 804/924-7421. Announced in Vol. 3, No. 2.

IEEE Computer Society Conf. on Pattern Recognition and Image Processing, Aug. 3-5, 1981, Dallas, TX. Announced in Vol. 2, No. 3.

7th International Joint Conference on Artificial Intelligence, August 24-28, 1981, Vancouver, Canada. Announced in Vol. 2, No. 3.

MEDIA SENSORS

Metalworking News, February 9, 1981, **Sensors to Spur Arc Welding by Robots.** Robotic arc welding would be more widely used in industry if only there were a device which could automatically guide an arc welding torch along a seam. Such a device would have to quickly determine the relative positions of the seam and torch to compensate for irregular fit-up and variations which occur during welding.

Two serious problems beset designers of arc welding sensors. First, the arc welding process creates noise which prevents accurate sensing. Second, since each type of weld has its own idiosyncracies, the welding sensor must be fairly general-purpose. Using a combination of various sensors may solve this problem—but the solution may be too expensive.

One simple approach now used in industry are electromechanical probes. These pressure-sensitive "fingers" ride in the welding groove just ahead of the torch and, when they contact the side of a seam, signal the welding system to move the probe and torch back towards the center of the seam. MG Welding products, Cyclomatic Industries, and Gullco International are among the companies that manufacture electromechanical sensors.

Most experts agree when George Munson of Unimation says, "There is a critical need for a non-contacting seam tracker." Hitachi America markets such a non-contact sensor as part of the Mr. Aros heavy duty welding robot. The sensor uses eddy currents—small electric currents induced by a changing magnetic field. Eddy current sensors, like electromechanical probes, work best for "wide open" joints and on heavy plate.

Another type of non-contact sensor measures the welding arc's voltage or current as the arc moves from side to side along the seam. The Merrick Corporation markets one such "through-the-arc" system, appropriately named Thuarc. Comet Tool Co., Advanced Robotics Corporation, and Karl Cloos Company are also trying to enter the through-the-arc sensor market. The through-the-arc approach is reaching the point of commercial viability.

In the long run, however, most experts agree that visual welding sensors are the most promising. These systems typically consist of a light source which illuminates the workpiece, a solid-state television camera which senses the image, and a microprocessor which analyzes the video data. The light source and the camera are normally focused at a point just ahead of the torch to avoid the harsh glare of the arc.

Most vision sensor systems use binary images, since they need less computer processing. Processing speed is critical in "real-time" welding applications and current systems are still a bit slow. However, as faster microprocessors and special-purpose hardware become available, processing speed should cease to be a problem.

Merrick is readying a visual device called the CT^2. It consists of a linear array camera, oriented at right angles to the weld seam, and a microprocessor that follows seam edges by keeping constant the video waveform of an edge.

Many laboratories—National Bureau of Standards, Unimation/Kawashi Ltd., and SRI International, for example—are developing more complex and versatile vision sensors using "structured light." With structured light sensors, a light pattern of known characteristics (parallel lines, for example) are bounced off the weld seam. From the deformations in the reflected pattern, the system can compute the distance to the weld and the width, depth, and shape of the weld groove. Automatix, Inc., will soon introduce a vision sensor using structured light as one of its options. It will be called Robovision II.

Ultimately, to achieve real adaptive control in arc welding, a sensor may have to look directly into the weld puddle—as a human welder does. And it may be years before such a system is developed.

Venture, March, 1981, **Venturers Bet on Artificial Intelligence.** After two decades of academic research in the field of Artificial Intelligence (AI), new companies are now creating products based on intelligent machines. Welding robots have quickly spread through the automobile industry, but other products based on artificial intelligence have taken longer to enter the industrial world. Major companies, such as IBM, Digital Equipment Corporation, General Electric, Hewlett-Packard, Schlumberger, and Texas Instruments are funding research projects—but none have yet marketed robotics-related products. This is fortunate for the small, startup robotics companies—such as Symbolics, Inc., Lisp Machines,

Inc., Machine Intelligence Corporation and Control Automation, Inc.

Some of the new companies are licensing existing technology, while others are developing their own. Charles Rosen, after twenty-one years with the Stanford Research Institute (SRI), left to form Machine Intelligence Corporation (MIC) and market the vision system which he developed in his Bay Area home. MIC's system allows a robot to compare an object it "sees" with stored models of various objects. It uses a black-and-white television image, and compares features such as perimeter and area to distinguish among many different objects. This system, which should allow a robot to do visual inspection or quality control on an assembly line, sells for $28,500.

Both Symbolics and Lisp Machines, Inc. (LMI) have based their products on LISP—the high-level, symbol-manipulation language commonly used in AI research. Among other potential applications of LISP, these companies might provide intelligent machines to train military personnel in areas where qualified instructors are scarce.

Control Automation's product, created by former Western Electric research engineer Gordon Robertson, is an industrial robot designed for small parts assembly. Robertson, who developed the prototype, expects to market the robot by the end of the year.

Engineering companies sometimes suffer from a lack of management expertise. But this is often solved by the firm's investors. At MIC, for example, a new management team was brought in at the same time three venture capital firms invested $500,000 in the firm. Founder Charles Rosen remained with the company as chief scientist and a member of the board.

In the case of Control Automation, venture capitalist Fred Adler invested $250,000 in return for two-thirds of the company's stock. The founders, Gordon Robertson and Tony Raddle, still hold the remaining shares.

LMI was founded when a businessman joined forces with a research scientist. Businessman Stephen Wyle manages the company's business affairs while Richard Greenblatt, formerly from MIT's AI laboratory, handles its technology. Most of LMI's $200,000 seed money came from their future customer, Control Data Corporation (CDC), which paid for their machines in advance. Wyle and Greenblatt each own 42½% of LMI and Scientific Cognitions, Inc.—a natural language research organization at CDC—owns the remaining 15%.

Another scientist from MIT's AI laboratory helped form Symbolics. Four years ago, Rusell Noftsker left MIT to found Perceptions Control, Inc., which manufactures microprocessor-controlled welding devices. A year ago, he began to form Symbolics. Robert P. Adams, who had helped start Scientific Data Systems, joined Noftsker and raised $435,000 from nine private investors. Adams's group is now enlisting the help of investment bankers to raise another $7 million. Symbolics's stock is evenly distributed between outsiders and the eighteen founders, eleven of whom come from MIT's AI laboratory.

Although Symbolics has a nonexclusive license from MIT to manufacture the computer and distribute the software, they have spent the last eight months adapting MIT's product to commercial needs. The first system, which Symbolics hopes to deliver by May, will cost about $160,000—inexpensive compared to the $1 million mainframes previously needed to run LISP programs. Symbolics is now developing a VLSI version of the LISP processor. The VLSI machine will quadruple the computing power of the MIT version and cost between $50,000 and $80,000. Adams optimistically expects sales to reach $80 million in five years and the firm to be ready to sell public shares in four.

Lisp Machines (LMI) also has a non-exclusive license from MIT. Unlike Symbolics, though, LMI is marketing the MIT hardware without major engineering changes. Texas Instruments and CDC have each ordered two LMI machines, and co-founder Wyle expects to sell more than ten in the first twelve months of production.

The new robotics companies are favored with both optimism and strong capital support. Venture capitalist Fred Adler's firm is ready to invest $2 million to $3 million in Control Automation, provided the company meets its goals. From his investment, Adler projects annual sales of $25 million in just five years.

Media Sensors *are brief summaries of robotics-related items that have appeared in the mass media. An attempt is made to paraphrase the content of the original item without altering the tone. The views expressed in these items are not necessarily those of Robotics Age. If you have an item you would like to contribute, send it along with a complete identification of its source, to:*

Media Sensors
Robotics Age
P. O. Box 725
La Canada, CA 91011

LETTERS

Dear Sirs:

I am hoping to start a club in the Northern New Jersey/New York City/Long Island area for anyone interested in building or working with robots. I would like to get a list together of all the people interested in joining such a club or working with robots.

Even if you are too far away to attend a meeting, keep in touch with me. I might hear of a local club in your area.

The meeting time and place have not been picked yet but will probably be on a week night in New York City.

If you have any questions or problems with robots, write me. I might be able to help.

David Smith
4505 Kennedy Blvd.
North Bergen, NJ 07047
201/856-4890

David:

There are two good sources you can try for the names of roboticists in your area. Contact Tom Carroll of the International Robotics Foundation, 7025 El Paseo St., Long Beach, CA 90815, and Stan Veit at the Robot Mart, 19 W. 34th St., NY, NY 10009.

To the Editors:

Keep up the good work! The magazine has a good balance. I especially like the Mar/Apr 1981 issue. Your magazine may well be filling the gap between the "trade journal" approach taken by SME's *Robotics Today* (which has little theoretical content) and the *IEEE Transactions on Pattern Analysis and Machine Intelligence*, which is too theoretical for the average reader. Maybe an analogy to *Byte* is better!

Greg Stanley

Dear Editor:

I am a student at Bronx High School of Science. I am currently involved in initiating a Robotics Club. We have a number of interested students in our school. I would like to introduce a course in Artificial Intelligence. I feel it is a worthwhile topic since the field will command the economy in the near future. By exposing the students of my school to this field, I hope to "spread the

word." Any publicity that you can provide might prove helpful in obtaining funds for our Club and hopefully lead to a course in Robotics.

Other students and I are involved in building an Artificial Intelligence System for Westinghouse. I am already involved in founding a new corporation, National Cybernetics, Inc., which will deal with the design and sales of Home Robot Systems and computer oriented devices.

Gregory Xikes
President of Robotics Club
Bronx High School of Science
75 W. 205th St.
Bronx, NY 10468

Wants More on PWM Motor Control

Dear Sir:

I am building a robot and have run into a problem with the speed control circuit for the motorized wheels. I have been using the book "How to Build a Computer Controlled Robot" for reference without much success. This is due to the fact that I am forced to use Radio Shack parts, which are always being updated, and therefore I have trouble finding good replacements.

The robot uses two motorized wheels which draw seven amps each at twelve volts. The two wheels have separate Rev/For. controls, connected to the Micro., so that it might turn by putting one wheel in forward and one in reverse. The speed must also be Micro. controlled by use of on/off cycles. However the speed for each wheel does not have to be separately controlled. I need a design that uses up-to-date Radio Shack parts, and is easy to build.

Douglas McClennen
220 Locust St., Apt. 15B
Philadelphia, PA 19106

Douglas:

Whenever parts are discontinued it always causes difficulty for experimenters who are trying to build something "by the book." It would be most considerate to the customer if manufacturers would provide a substitution chart for parts that have been phased out. In almost all cases, there are a variety of common components that would substitute quite well. Let's hope the powers-that-be in Fort Worth (and elsewhere) are listening. (MBW take note!)

In the construction articles in Robotics Age, *we list the source of any hard-to-get part with the article. If no source is given, the part can usually be obtained from one of the electronics parts suppliers whose ads appear in other popular magazines.*

As to your request for a new design, we have more Pulse-Width Modulation (PWM) circuitry in the works. By far the best PWM circuit for robotics applications is the Cuk Converter, which provides virtually noise-free DC power amplification and is readily interfaced to micros. (See "Advances in Switched-Mode Power Conversion" in *Robotics Age*, V1, n2, and V2, n2) *This converter can be configured to servo control AC motors, as we will show in an article devoted to this application.*

—AMT

CLASSIFIED

Our classified advertising section is for readers wishing to buy, sell or trade hardware of software. The price is 30¢ per word. The first word is set in all caps. Minimum 20 words. Send copy with check to ROBOTICS AGE CLASSIFIED, PO Box 725, La Canada, CA 91011.

Erratum

In our last issue, Mar/Apr 1981, we inadvertently omitted the byline on the article, "Video Signal Input." This real-time video digitizer was designed by Raymond Eskenazi of Culver City, Calif. There are also some corrections to make to the digitizer circuit given on pages 8 & 9 of that article.

IC12, like the other counter ICs, is a 74LS163. All 74LS74 dual "D" flip-flops should have their preset lines (pins 4 & 10) tied to +5V. This detail was omitted on the FFs that produce the "ODD FIELD" and interrupt handshake signals. On the video sync generator, IC1, input pins 2 and 4 through 7 should be tied to +5V.

BOOKS

The following is a list of books received by Robotics Age *in the past few months. Though not an exhaustive bibliography, the list gives some of the important new books on Robotics and related topics. We regret that we cannot review all the books we receive. We intend the list below as a grateful acknowledgement to the publishers who have sent us these books.*

Gonzalez, Rafael C. and Thomason, Michael G., *Syntactic Pattern Recognition*. Reading, Massachusetts: Addison-Wesley, 1978.

Gonzalez, Rafael C. and Wintz, Paul. *Digital Image Processing*. Reading, Massachusetts: Addison-Wesley, 1977.

Halevi, Gideon. *The Role of Computers in Manufacturing Processes*. New York: John Wiley & Sons, 1980.

Kent, Ernest W. *The Brains of Men and Machines*. New York: McGraw-Hill, 1981.

Sager, Naomi. *Natural Language Information Processing*. Reading, Massachusetts: Addison-Wesley, 1981.

Tiberghien, Jacques. *The PASCAL Handbook*. Berkeley, California: Sybex, 1981.

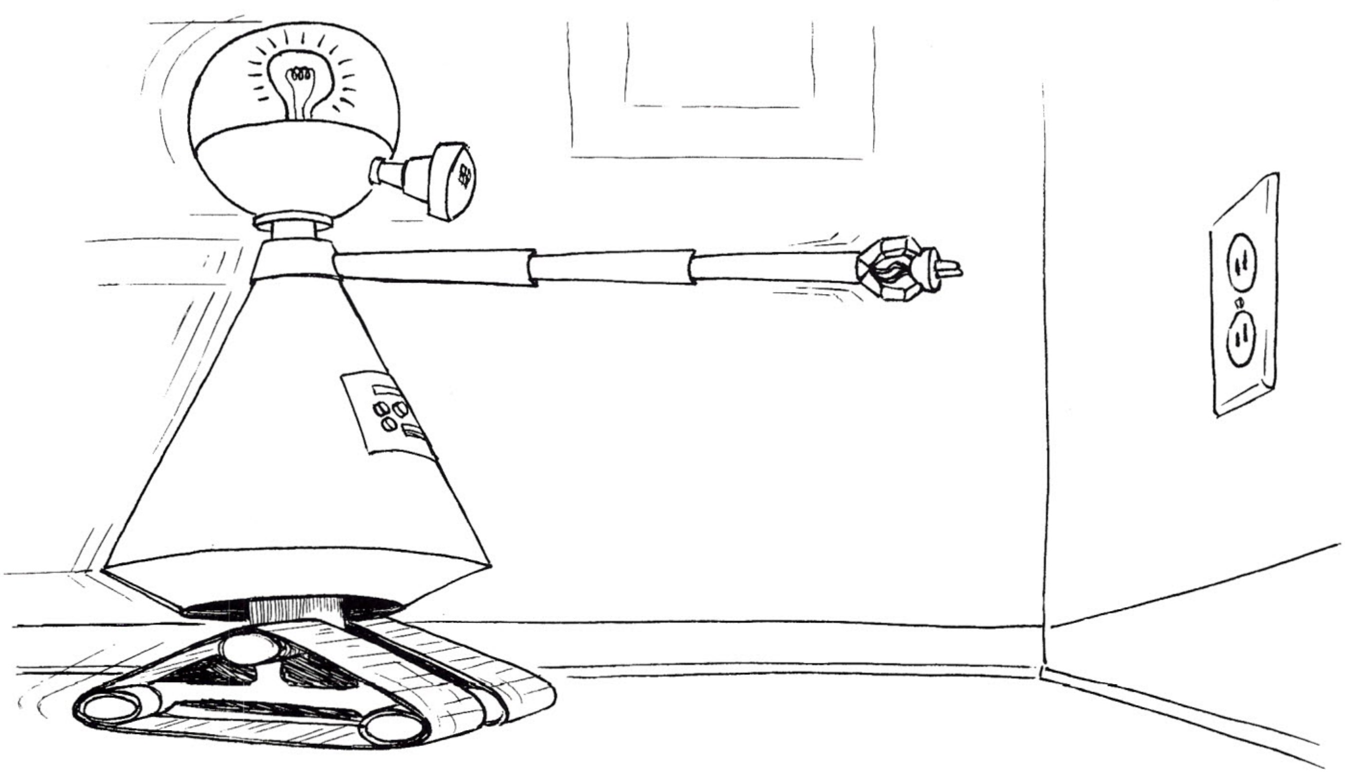
Weinstein, Martin Bradley. *Android Design: Practical Approaches for Robot Builders*. Rochelle Park, New Jersey: Hayden Book Company, 1981.

Winston, Patrick H., and Horne, Berthold. *LISP*. Reading, Massachusetts: Addison-Wesley, 1980.

A CALL FOR BOOK REVIEWS

Have you read one of the books listed above? Has it been useful in your work? Share your thoughts about it with our readers. We are always looking for reviews of recent and important publications on Robotics or Artificial Intelligence.

Reviews should be typewritten, double-spaced, on standard 8½ by 11 inch paper. They may run anywhere from two to five manuscript pages. We pay up to $50 per magazine page.



—Socket to me—Socket to me—Socket to me—Socket to me—

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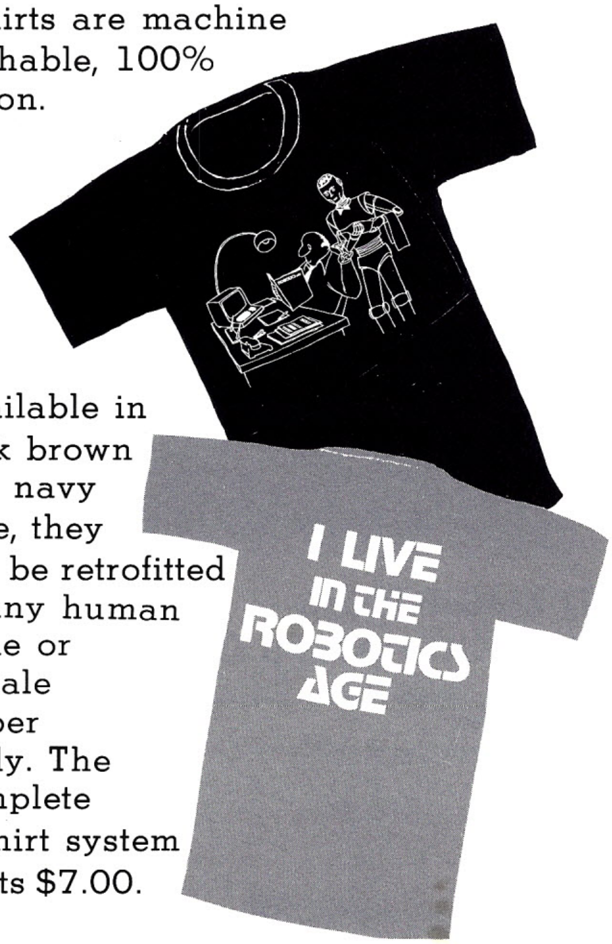
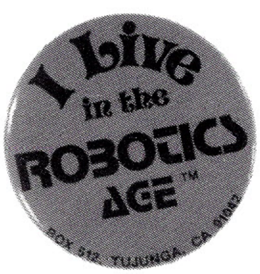


Available in dark brown and navy blue, they can be retrofitted to any human male or female upper body. The complete T-shirt system costs $7.00.



For those who insist on wearing metal, ROBOTICS AGE buttons are available for $.50 each. On all orders, be sure to add $1.00 for postage and handling.

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- Program segmentability
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- Built-in powerful string-handling features

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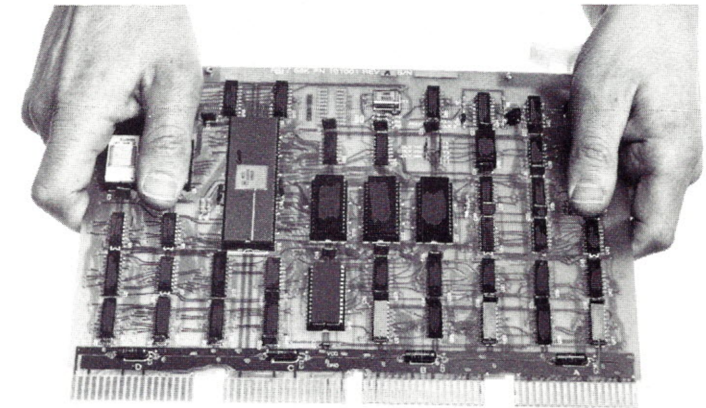

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